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Aoki

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(54) **IMAGE CAPTURING METHOD AND IMAGE CAPTURING APPARATUS FOR ILLUMINATING SUBJECT**

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(21) Appl. No.: **14/108,589**

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
H04N 5/235 (2006.01)
H04N 5/217 (2011.01)

(52) **U.S. Cl.**
CPC ***H04N 5/2354*** (2013.01); ***H04N 5/217*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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(57) **ABSTRACT**

An image capturing method includes: continuously generating, using a processor, one or more OFF images in which the subject is captured with the illumination turned OFF, for a first number of times; continuously generating, using the processor, ON images in which the subject is captured with the illumination turned ON, for a second number of times; continuously generating, using the processor, one or more OFF images in which the subject is captured with the illumination turned OFF, for the first number of times; computing, using the processor, a difference image between each of the generated ON images and the OFF image corresponding to the ON image among the generated OFF images; and integrating, using the processor, the computed difference images.

14 Claims, 17 Drawing Sheets

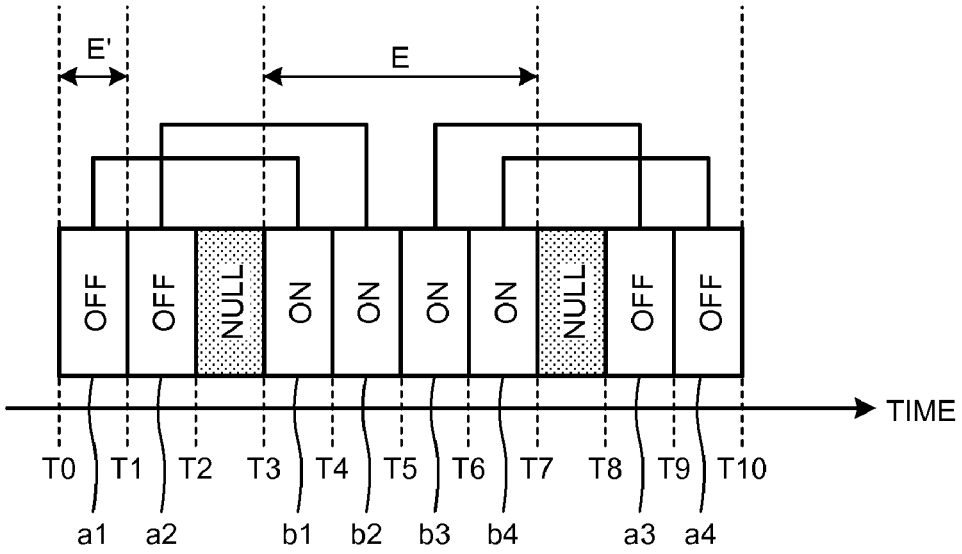

FIG.1

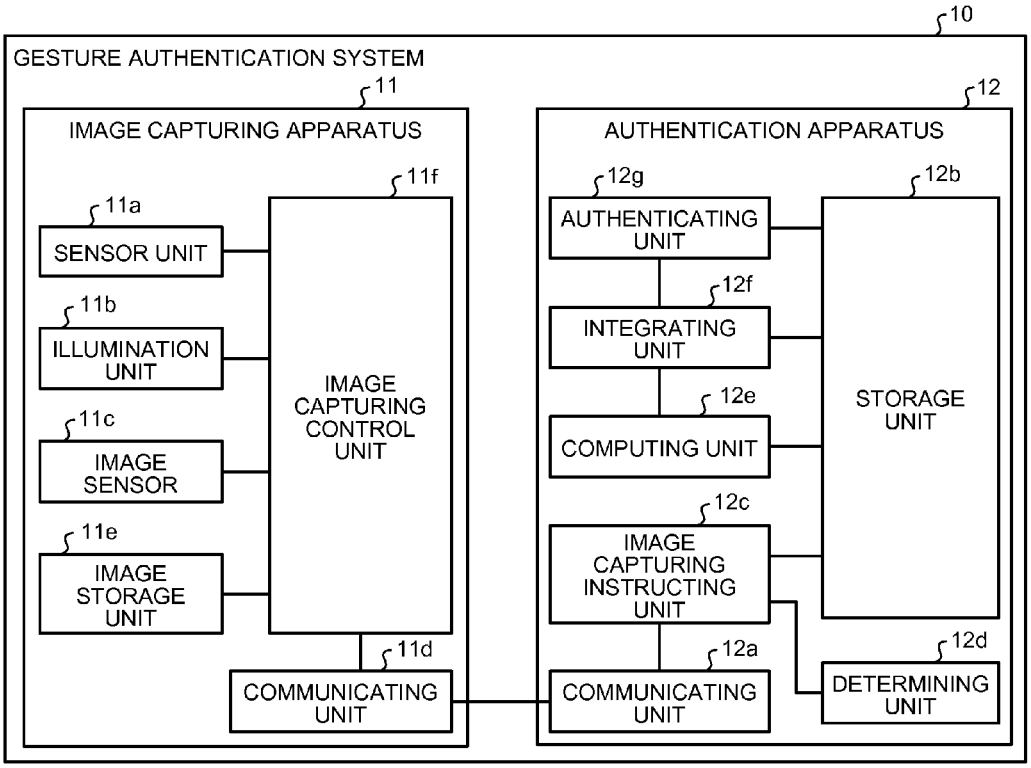
10
GESTURE AUTHENTICATION SYSTEM
11
IMAGE CAPTURING APPARATUS
11a
SENSOR UNIT
11b
ILLUMINATION UNIT
11c
IMAGE SENSOR
11e
IMAGE STORAGE UNIT
11f
IMAGE CAPTURING CONTROL UNIT
11d
COMMUNICATING UNIT
12
AUTHENTICATION APPARATUS
12g
AUTHENTICATING UNIT
12f
INTEGRATING UNIT
12e
COMPUTING UNIT
12c
IMAGE CAPTURING INSTRUCTING UNIT
12a
COMMUNICATING UNIT
12b
STORAGE UNIT
12d
DETERMINING UNIT

FIG.2

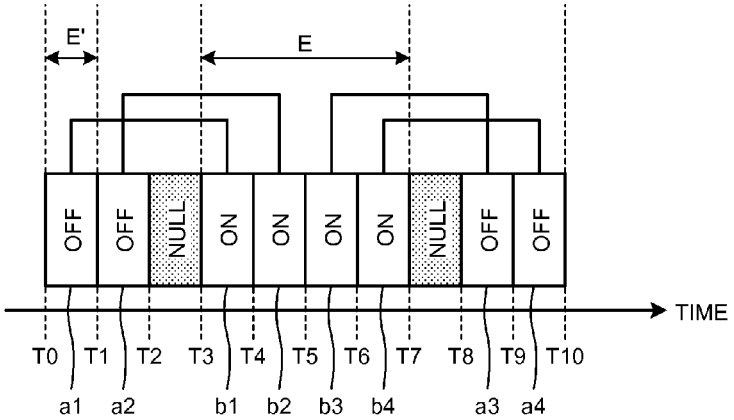
E'
E
OFF
OFF
NULL
ON
ON
ON
ON
NULL
OFF
OFF
TIME
T0
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
a1
a2
b1
b2
b3
b4
a3
a4

FIG.3

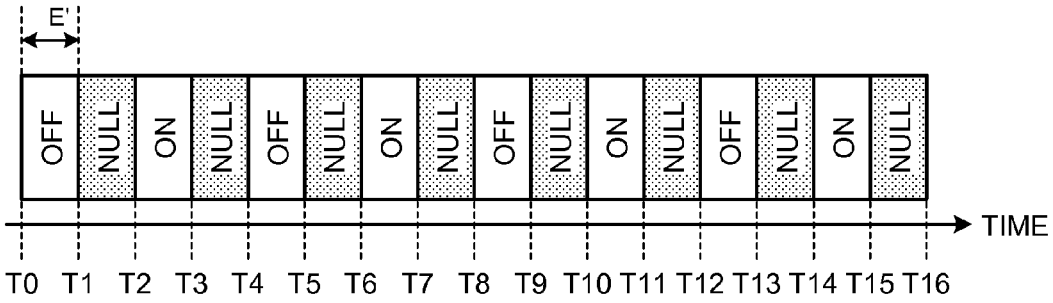
E'
OFF
NULL
ON
NULL
OFF
NULL
ON
NULL
OFF
NULL
ON
NULL
OFF
NULL
ON
NULL
TIME
T0 T1 T2 T3 T4 T5 T6 T7 T8 T9 T10 T11 T12 T13 T14 T15 T16

FIG.4

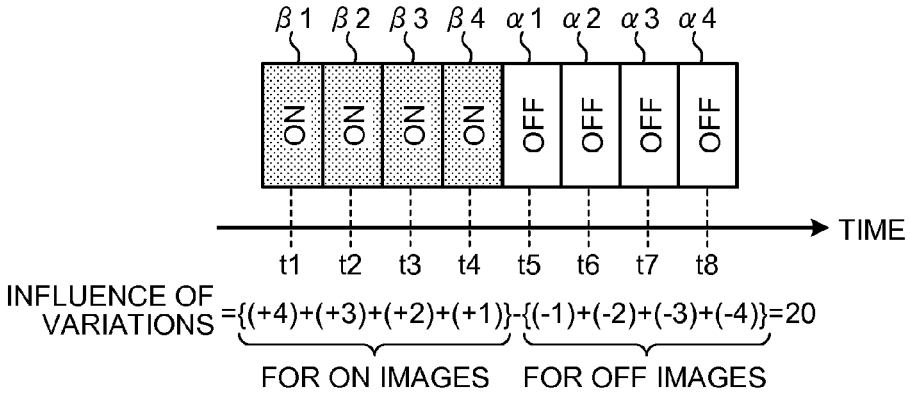
β1 β2 β3 β4 α1 α2 α3 α4
ON
ON
ON
ON
OFF
OFF
OFF
OFF
TIME
t1 t2 t3 t4 t5 t6 t7 t8
INFLUENCE OF VARIATIONS ={(+4)+(+3)+(+2)+(+1)}-{(-1)+(-2)+(-3)+(-4)}=20
FOR ON IMAGES
FOR OFF IMAGES

FIG.5

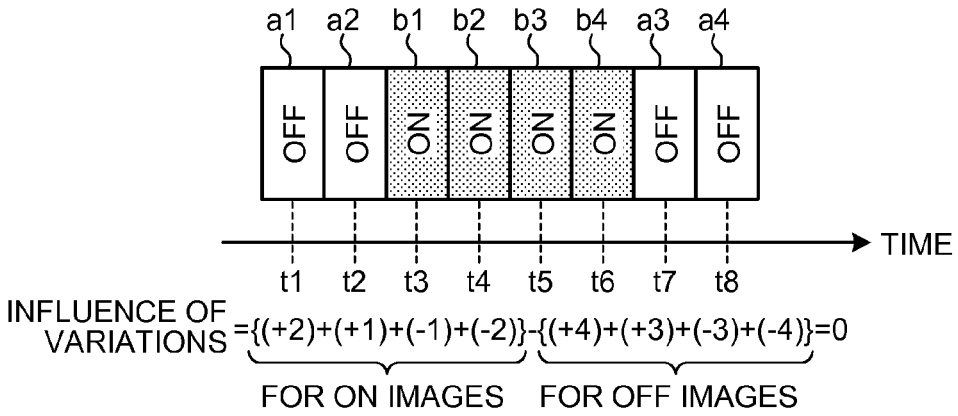
a1
a2
b1
b2
b3
b4
a3
a4
OFF
OFF
ON
ON
ON
ON
OFF
OFF
TIME
t1
t2
t3
t4
t5
t6
t7
t8
INFLUENCE OF VARIATIONS
={(+2)+(+1)+(-1)+(-2)}-{(+4)+(+3)+(-3)+(-4)}=0
FOR ON IMAGES
FOR OFF IMAGES

FIG.6

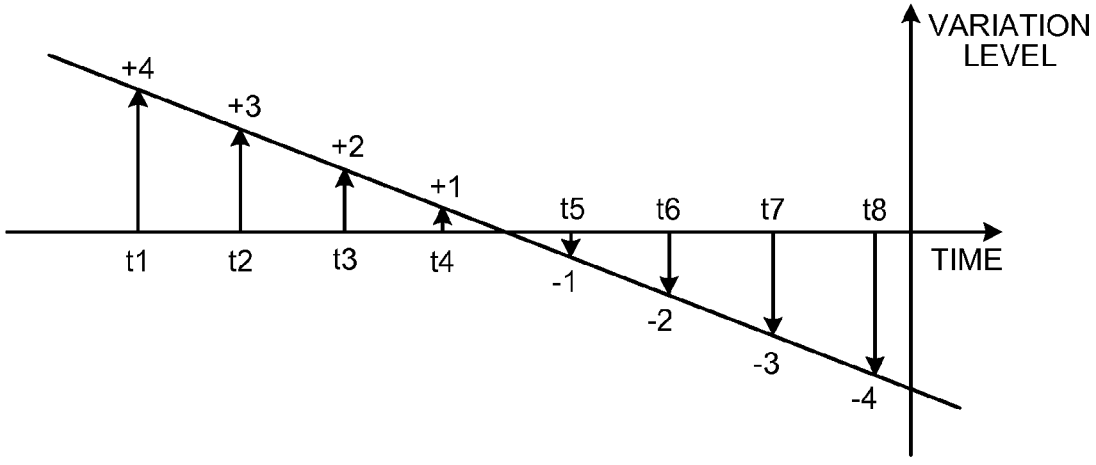
VARIATION LEVEL
+4
+3
+2
+1
t5
t6
t7
t8
t1
t2
t3
t4
TIME
-1
-2
-3
-4

FIG.7

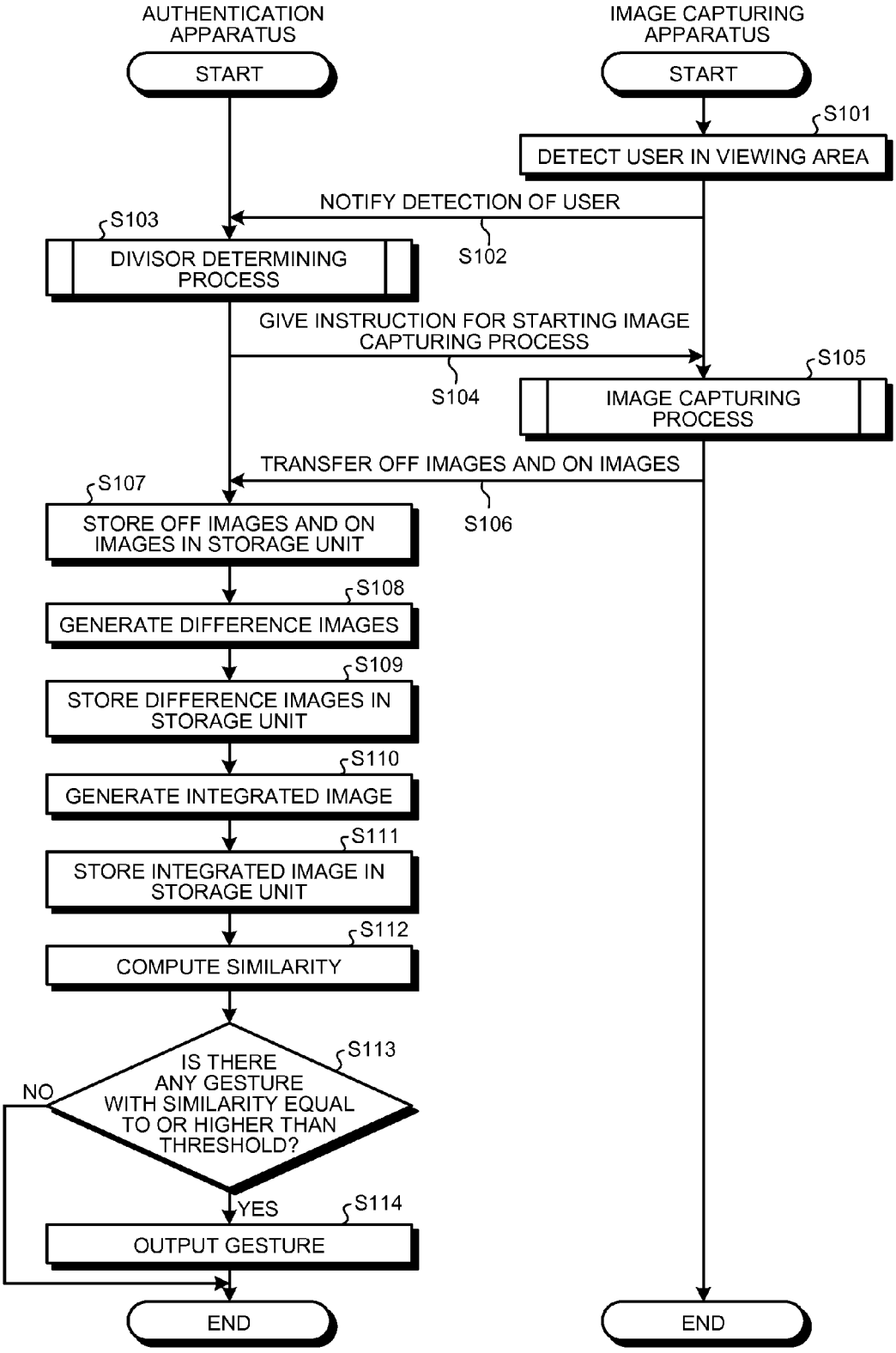
AUTHENTICATION APPARATUS
START
IMAGE CAPTURING APPARATUS
START
S101
DETECT USER IN VIEWING AREA
NOTIFY DETECTION OF USER
S102
S103
DIVISOR DETERMINING PROCESS
GIVE INSTRUCTION FOR STARTING IMAGE CAPTURING PROCESS
S104
S105
IMAGE CAPTURING PROCESS
TRANSFER OFF IMAGES AND ON IMAGES
S106
S107
STORE OFF IMAGES AND ON IMAGES IN STORAGE UNIT
S108
GENERATE DIFFERENCE IMAGES
S109
STORE DIFFERENCE IMAGES IN STORAGE UNIT
S110
GENERATE INTEGRATED IMAGE
S111
STORE INTEGRATED IMAGE IN STORAGE UNIT
S112
COMPUTE SIMILARITY
S113
IS THERE ANY GESTURE WITH SIMILARITY EQUAL TO OR HIGHER THAN THRESHOLD?
NO
YES
S114
OUTPUT GESTURE
END
END

FIG.8

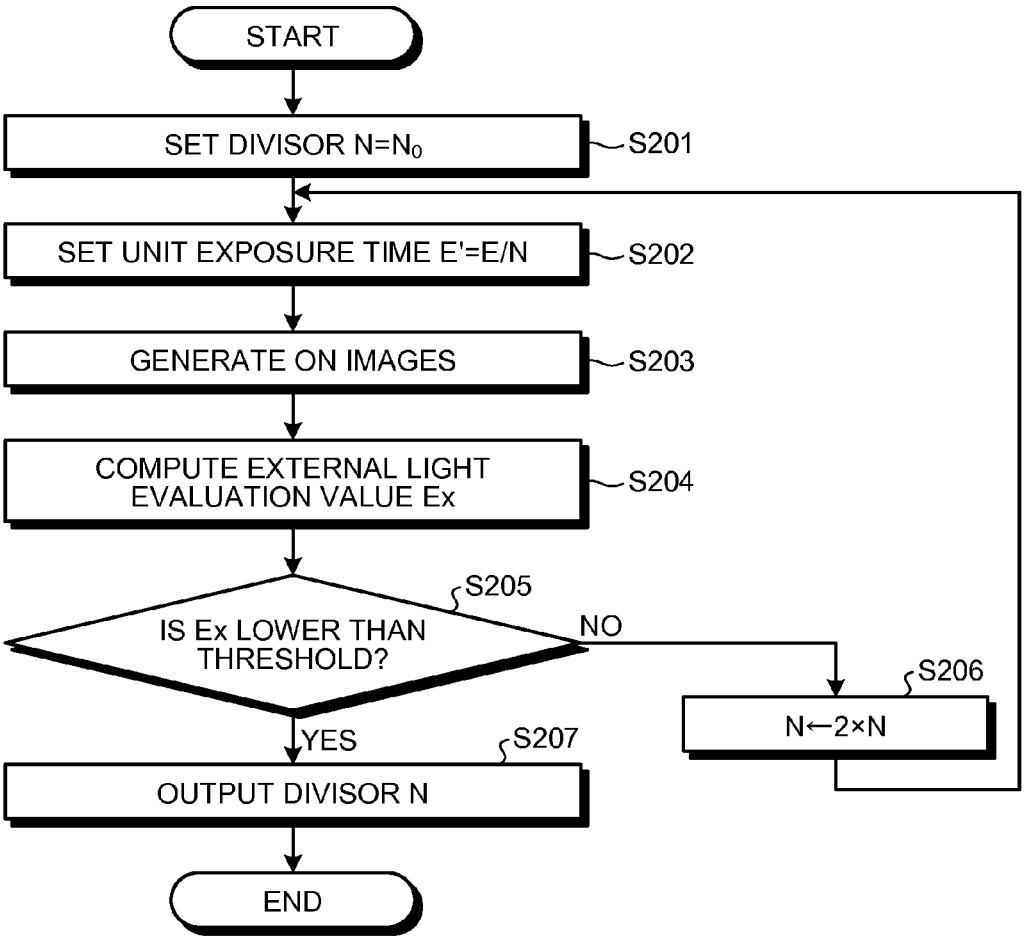
START
SET DIVISOR N=N0
S201
SET UNIT EXPOSURE TIME E'=E/N
S202
GENERATE ON IMAGES
S203
COMPUTE EXTERNAL LIGHT EVALUATION VALUE Ex
S204
S205
IS Ex LOWER THAN THRESHOLD?
NO
S206
N←2×N
YES
S207
OUTPUT DIVISOR N
END

FIG.9

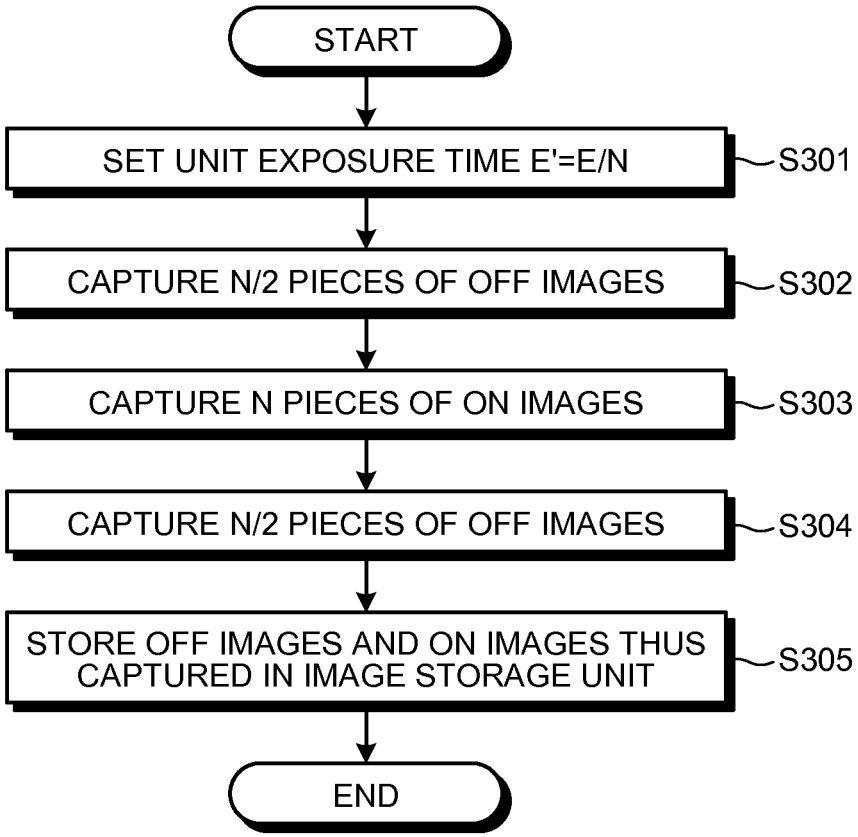
START
SET UNIT EXPOSURE TIME E'=E/N
S301
CAPTURE N/2 PIECES OF OFF IMAGES
S302
CAPTURE N PIECES OF ON IMAGES
S303
CAPTURE N/2 PIECES OF OFF IMAGES
S304
STORE OFF IMAGES AND ON IMAGES THUS CAPTURED IN IMAGE STORAGE UNIT
S305
END

FIG.10

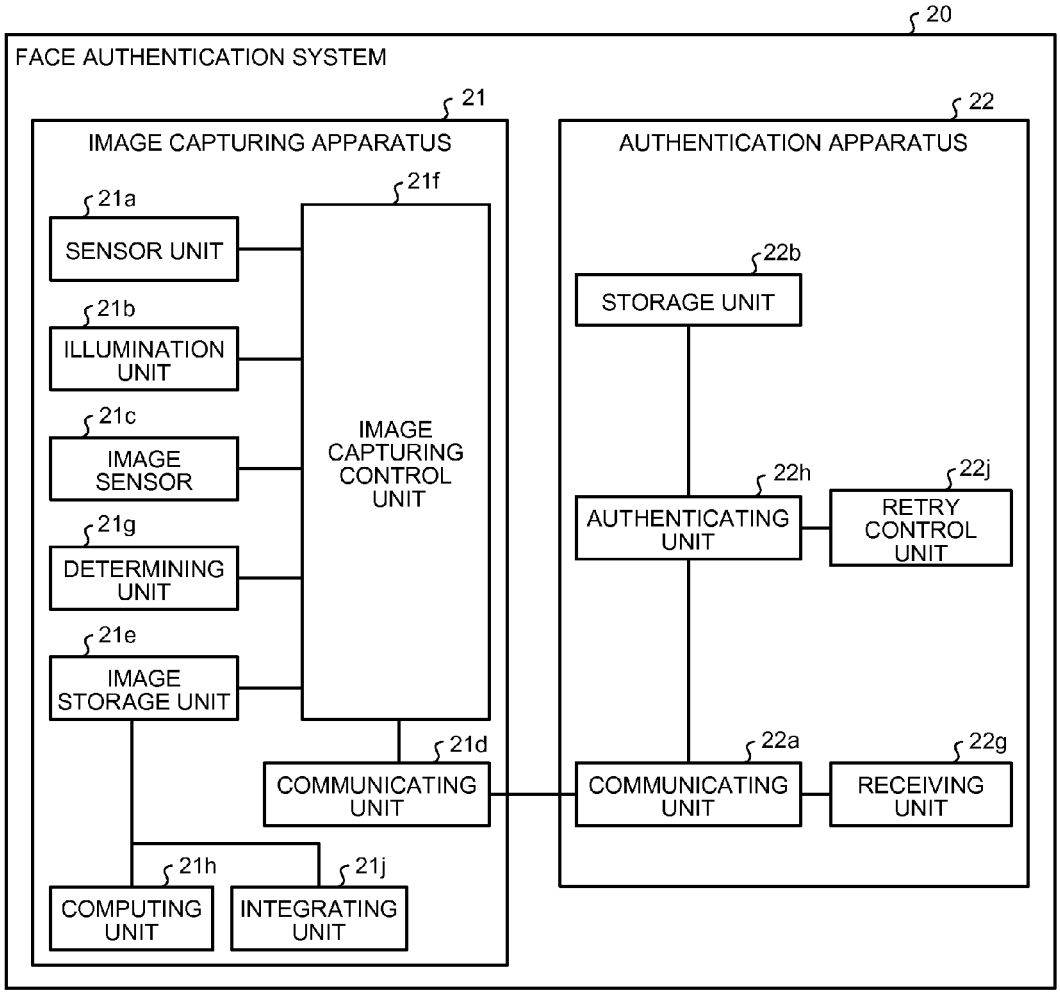
20
FACE AUTHENTICATION SYSTEM
21
IMAGE CAPTURING APPARATUS
21a
SENSOR UNIT
21b
ILLUMINATION UNIT
21c
IMAGE SENSOR
21g
DETERMINING UNIT
21e
IMAGE STORAGE UNIT
21f
IMAGE CAPTURING CONTROL UNIT
21d
COMMUNICATING UNIT
21h
COMPUTING UNIT
21j
INTEGRATING UNIT
22
AUTHENTICATION APPARATUS
22b
STORAGE UNIT
22h
AUTHENTICATING UNIT
22j
RETRY CONTROL UNIT
22a
COMMUNICATING UNIT
22g
RECEIVING UNIT

FIG.11

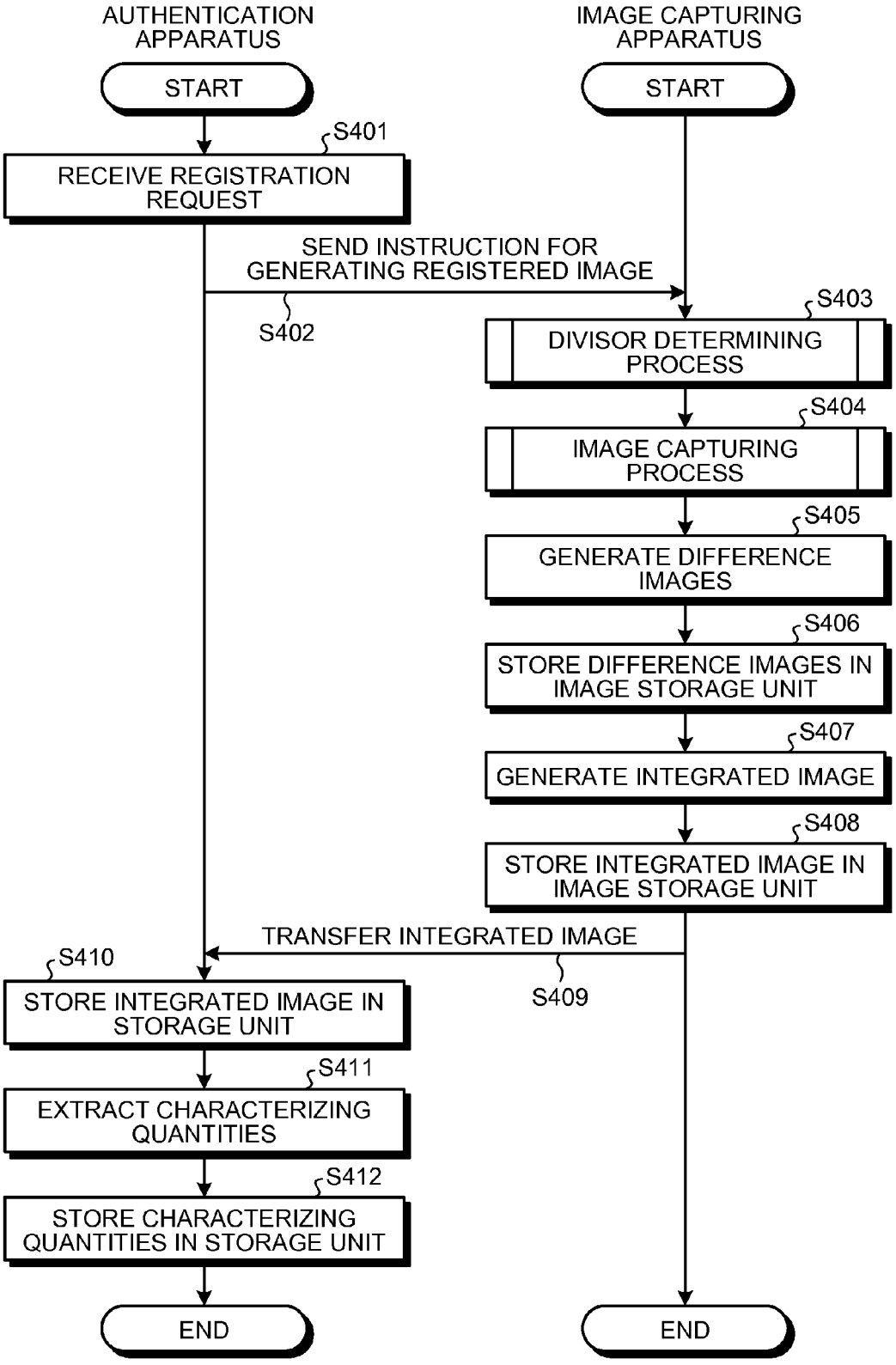
AUTHENTICATION APPARATUS
IMAGE CAPTURING APPARATUS
START
START
S401
RECEIVE REGISTRATION REQUEST
SEND INSTRUCTION FOR GENERATING REGISTERED IMAGE
S402
S403
DIVISOR DETERMINING PROCESS
S404
IMAGE CAPTURING PROCESS
S405
GENERATE DIFFERENCE IMAGES
S406
STORE DIFFERENCE IMAGES IN IMAGE STORAGE UNIT
S407
GENERATE INTEGRATED IMAGE
S408
STORE INTEGRATED IMAGE IN IMAGE STORAGE UNIT
TRANSFER INTEGRATED IMAGE
S409
S410
STORE INTEGRATED IMAGE IN STORAGE UNIT
S411
EXTRACT CHARACTERIZING QUANTITIES
S412
STORE CHARACTERIZING QUANTITIES IN STORAGE UNIT
END
END

FIG.12

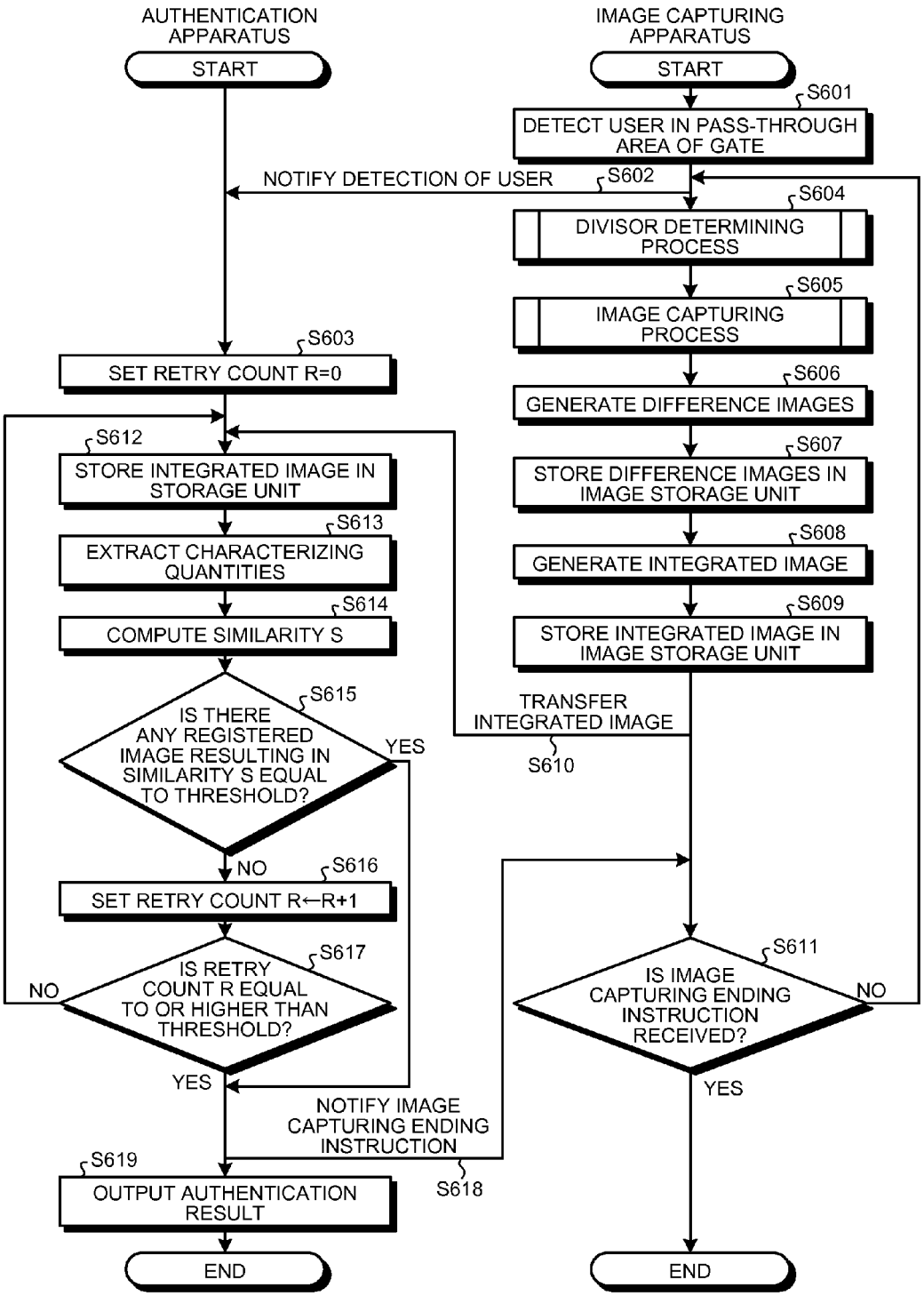
AUTHENTICATION APPARATUS
START
IMAGE CAPTURING APPARATUS
START
S601
DETECT USER IN PASS-THROUGH AREA OF GATE
NOTIFY DETECTION OF USER
S602
S604
DIVISOR DETERMINING PROCESS
S605
IMAGE CAPTURING PROCESS
S603
SET RETRY COUNT R=0
S606
GENERATE DIFFERENCE IMAGES
S612
STORE INTEGRATED IMAGE IN STORAGE UNIT
S607
STORE DIFFERENCE IMAGES IN IMAGE STORAGE UNIT
S613
EXTRACT CHARACTERIZING QUANTITIES
S608
GENERATE INTEGRATED IMAGE
S614
COMPUTE SIMILARITY S
S609
STORE INTEGRATED IMAGE IN IMAGE STORAGE UNIT
S615
IS THERE ANY REGISTERED IMAGE RESULTING IN SIMILARITY S EQUAL TO THRESHOLD?
YES
TRANSFER INTEGRATED IMAGE
S610
NO
S616
SET RETRY COUNT R←R+1
S617
IS RETRY COUNT R EQUAL TO OR HIGHER THAN THRESHOLD?
NO
S611
IS IMAGE CAPTURING ENDING INSTRUCTION RECEIVED?
NO
YES
YES
NOTIFY IMAGE CAPTURING ENDING INSTRUCTION
S618
S619
OUTPUT AUTHENTICATION RESULT
END
END

FIG.13

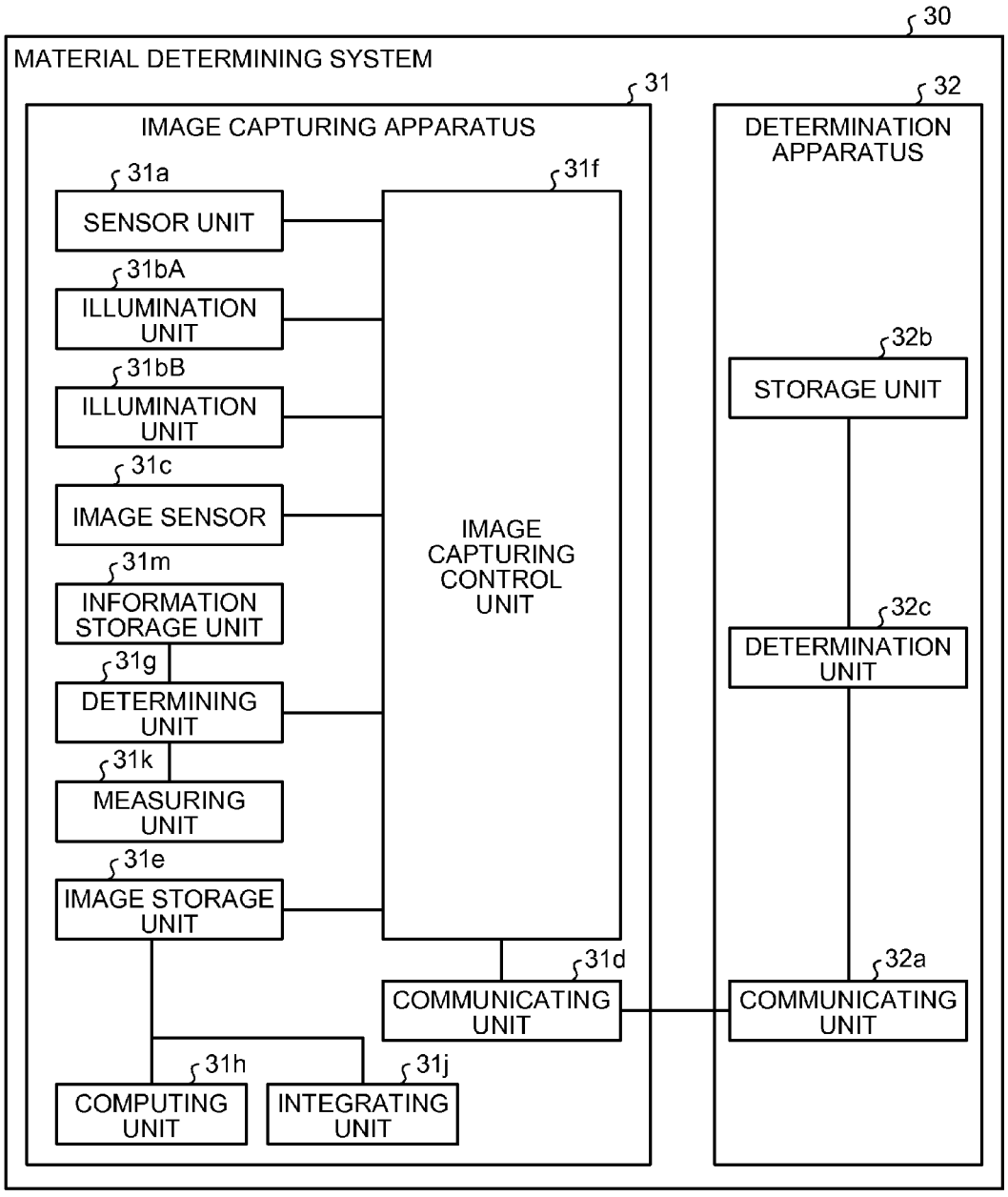
30
MATERIAL DETERMINING SYSTEM
31
IMAGE CAPTURING APPARATUS
32
DETERMINATION APPARATUS
31a
SENSOR UNIT
31bA
ILLUMINATION UNIT
31bB
ILLUMINATION UNIT
31c
IMAGE SENSOR
31m
INFORMATION STORAGE UNIT
31g
DETERMINING UNIT
31k
MEASURING UNIT
31e
IMAGE STORAGE UNIT
31f
IMAGE CAPTURING CONTROL UNIT
31d
COMMUNICATING UNIT
31h
COMPUTING UNIT
31j
INTEGRATING UNIT
32b
STORAGE UNIT
32c
DETERMINATION UNIT
32a
COMMUNICATING UNIT

FIG.14

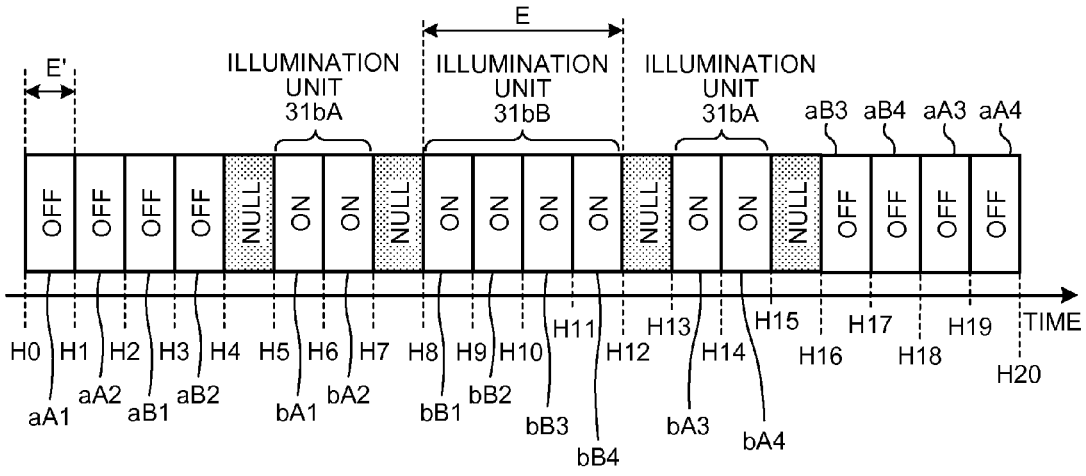

FIG.15

OUTPUT CURRENT	DIVISOR N
TO 10mA	0
11mA TO 20mA	1
21mA TO 30mA	2
31mA TO 40mA	4

FIG.16

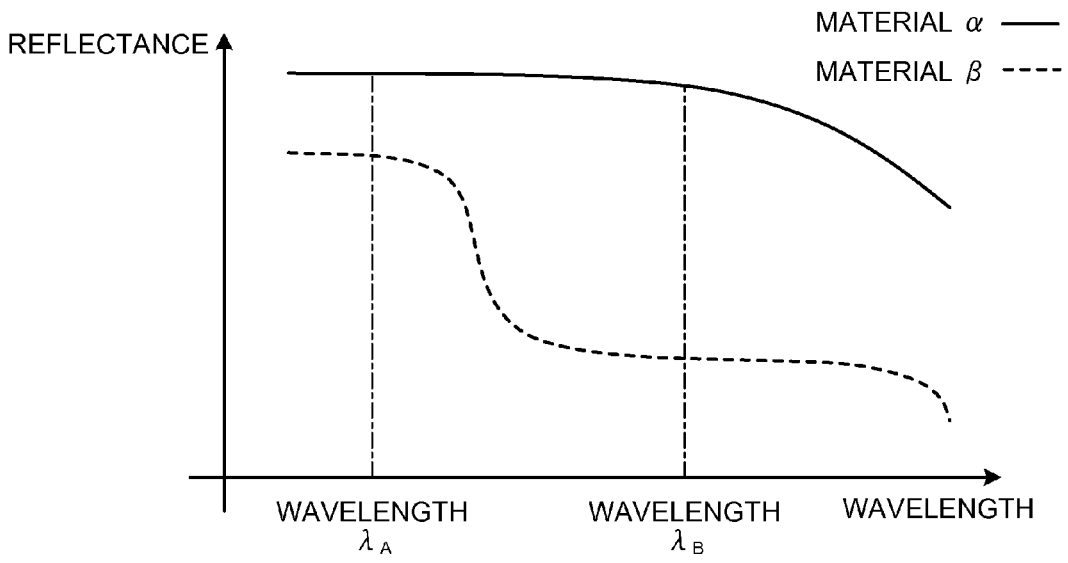
REFLECTANCE
MATERIAL α
MATERIAL β
WAVELENGTH
λA
WAVELENGTH
λB
WAVELENGTH

FIG.17

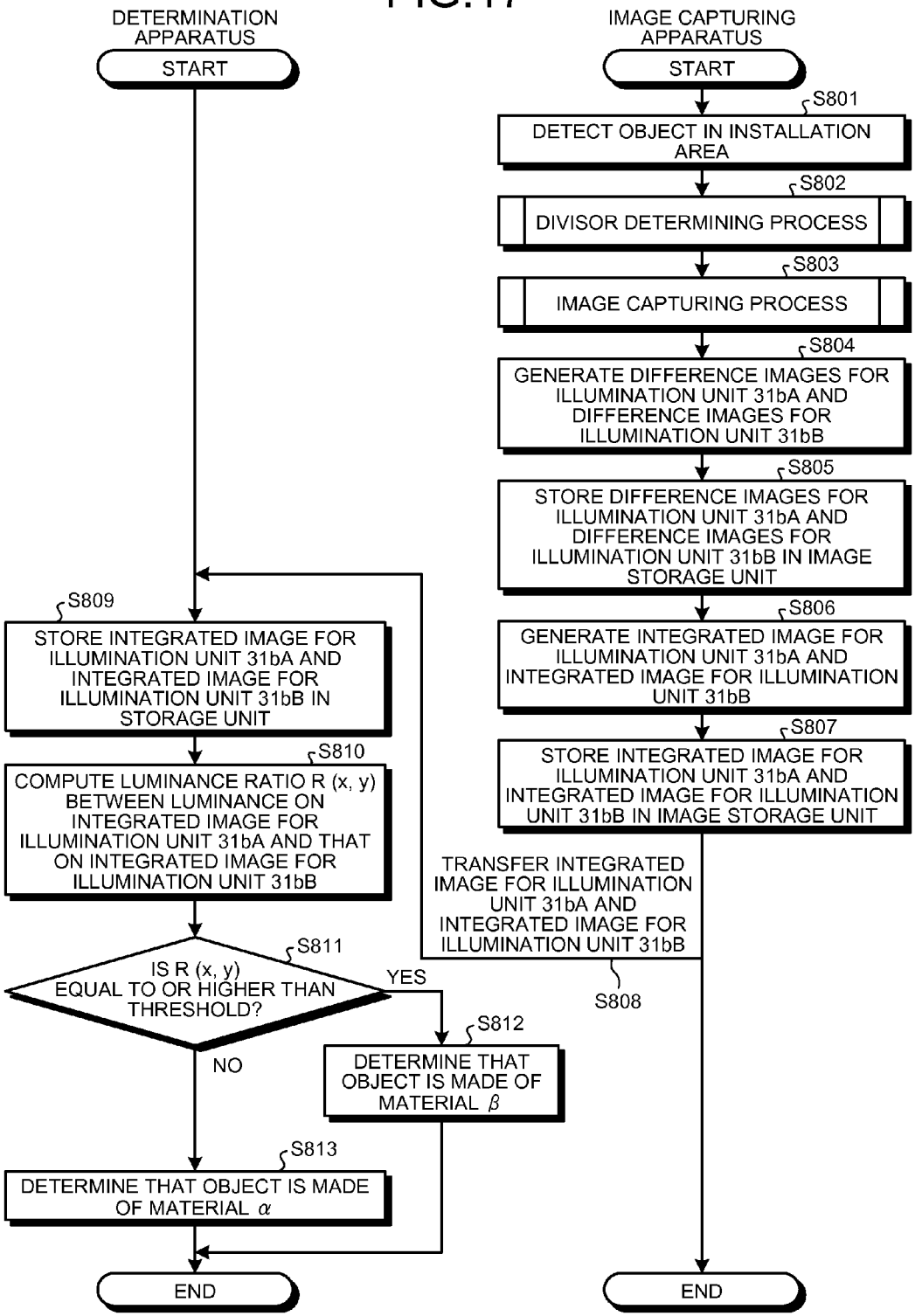
DETERMINATION APPARATUS
START
IMAGE CAPTURING APPARATUS
START
S801
DETECT OBJECT IN INSTALLATION AREA
S802
DIVISOR DETERMINING PROCESS
S803
IMAGE CAPTURING PROCESS
S804
GENERATE DIFFERENCE IMAGES FOR ILLUMINATION UNIT 31bA AND DIFFERENCE IMAGES FOR ILLUMINATION UNIT 31bB
S805
STORE DIFFERENCE IMAGES FOR ILLUMINATION UNIT 31bA AND DIFFERENCE IMAGES FOR ILLUMINATION UNIT 31bB IN IMAGE STORAGE UNIT
S806
GENERATE INTEGRATED IMAGE FOR ILLUMINATION UNIT 31bA AND INTEGRATED IMAGE FOR ILLUMINATION UNIT 31bB
S807
STORE INTEGRATED IMAGE FOR ILLUMINATION UNIT 31bA AND INTEGRATED IMAGE FOR ILLUMINATION UNIT 31bB IN IMAGE STORAGE UNIT
TRANSFER INTEGRATED IMAGE FOR ILLUMINATION UNIT 31bA AND INTEGRATED IMAGE FOR ILLUMINATION UNIT 31bB
S808
S809
STORE INTEGRATED IMAGE FOR ILLUMINATION UNIT 31bA AND INTEGRATED IMAGE FOR ILLUMINATION UNIT 31bB IN STORAGE UNIT
S810
COMPUTE LUMINANCE RATIO R (x, y) BETWEEN LUMINANCE ON INTEGRATED IMAGE FOR ILLUMINATION UNIT 31bA AND THAT ON INTEGRATED IMAGE FOR ILLUMINATION UNIT 31bB
S811
IS R (x, y) EQUAL TO OR HIGHER THAN THRESHOLD?
YES
NO
S812
DETERMINE THAT OBJECT IS MADE OF MATERIAL β
S813
DETERMINE THAT OBJECT IS MADE OF MATERIAL α
END
END

FIG.18

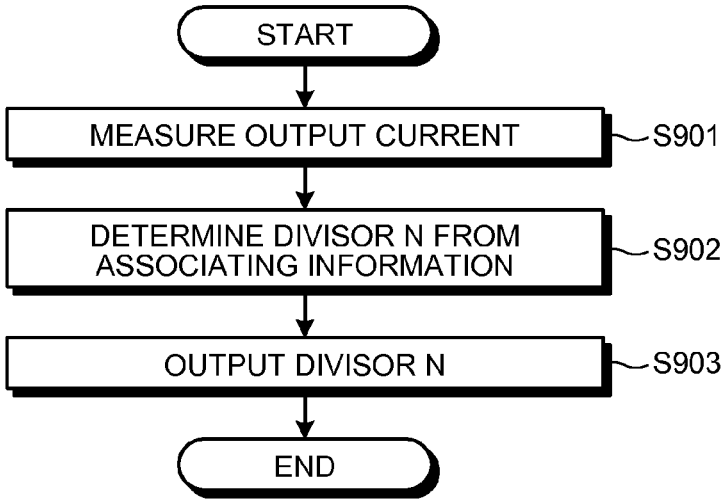
START
MEASURE OUTPUT CURRENT
S901
DETERMINE DIVISOR N FROM ASSOCIATING INFORMATION
S902
OUTPUT DIVISOR N
S903
END

FIG.19

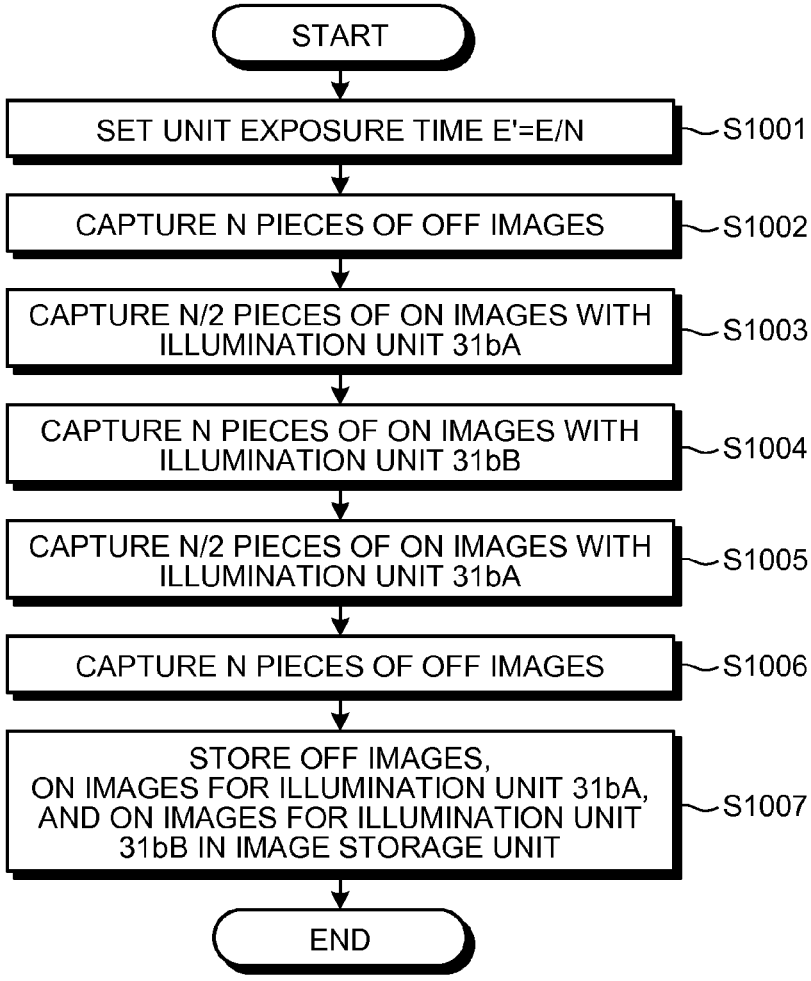
START
SET UNIT EXPOSURE TIME E'=E/N
S1001
CAPTURE N PIECES OF OFF IMAGES
S1002
CAPTURE N/2 PIECES OF ON IMAGES WITH ILLUMINATION UNIT 31bA
S1003
CAPTURE N PIECES OF ON IMAGES WITH ILLUMINATION UNIT 31bB
S1004
CAPTURE N/2 PIECES OF ON IMAGES WITH ILLUMINATION UNIT 31bA
S1005
CAPTURE N PIECES OF OFF IMAGES
S1006
STORE OFF IMAGES, ON IMAGES FOR ILLUMINATION UNIT 31bA, AND ON IMAGES FOR ILLUMINATION UNIT 31bB IN IMAGE STORAGE UNIT
S1007
END

FIG.20

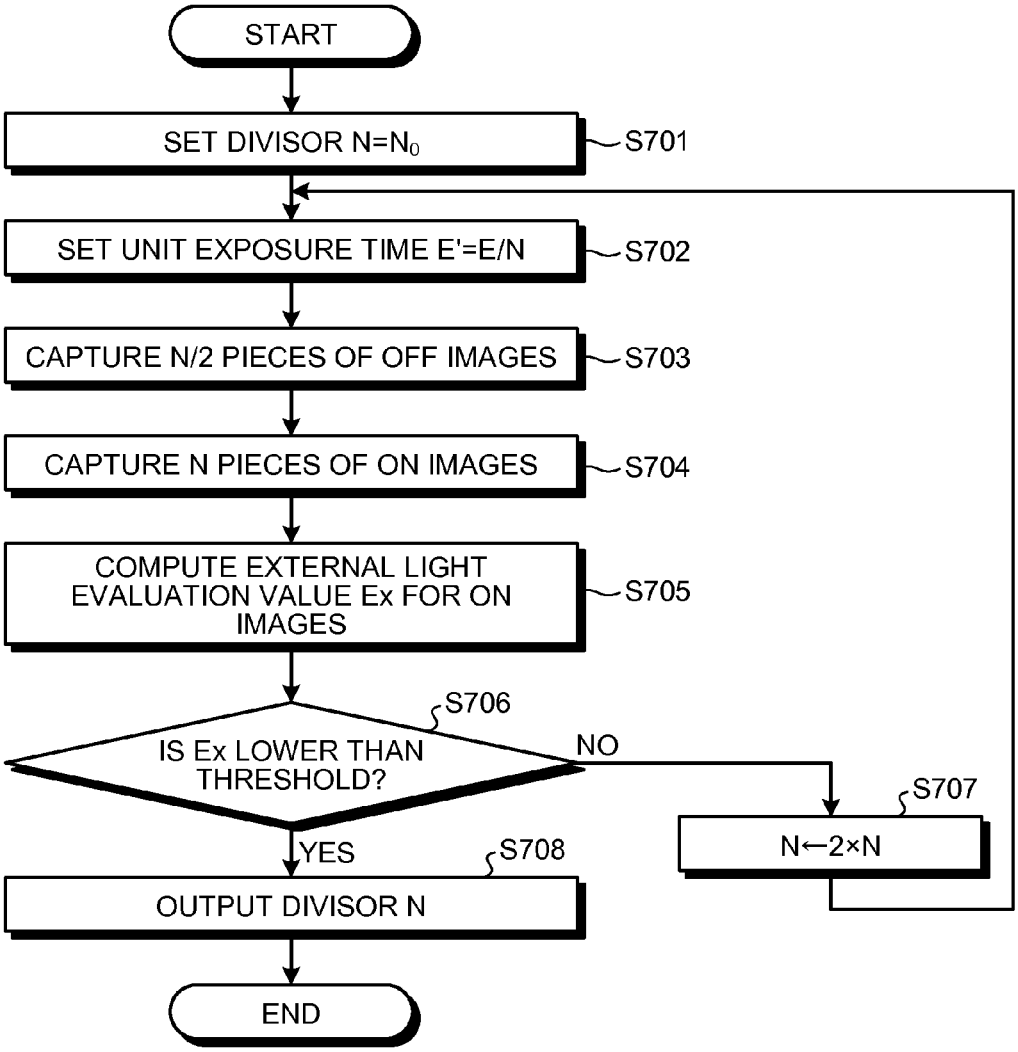
START
SET DIVISOR N=N0
S701
SET UNIT EXPOSURE TIME E'=E/N
S702
CAPTURE N/2 PIECES OF OFF IMAGES
S703
CAPTURE N PIECES OF ON IMAGES
S704
COMPUTE EXTERNAL LIGHT EVALUATION VALUE Ex FOR ON IMAGES
S705
S706
IS Ex LOWER THAN THRESHOLD?
NO
S707
N←2×N
YES
S708
OUTPUT DIVISOR N
END

FIG.21

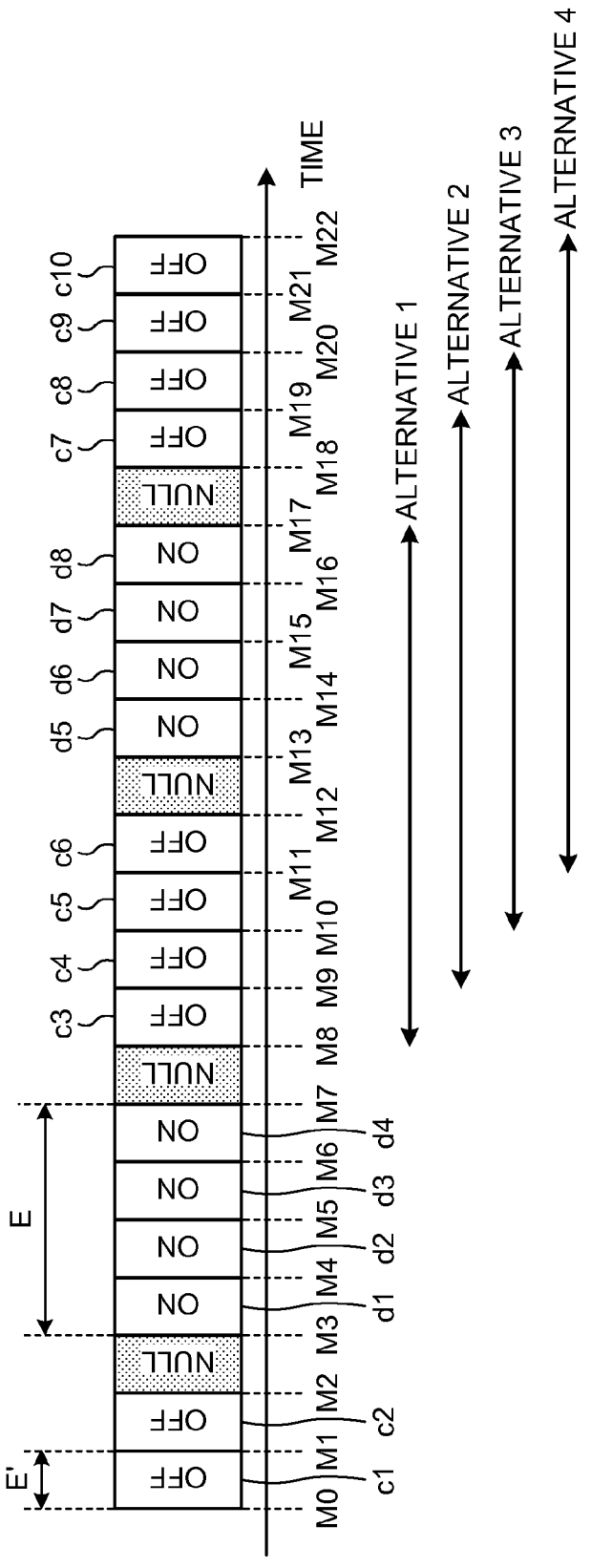
TIME
M0
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
M11
M12
M13
M14
M15
M16
M17
M18
M19
M20
M21
M22
c1
c2
d1
d2
d3
d4
c3
c4
c5
c6
d5
d6
d7
d8
c7
c8
c9
c10
E'
E
OFF
NULL
NO
ALTERNATIVE 1
ALTERNATIVE 2
ALTERNATIVE 3
ALTERNATIVE 4

FIG.22

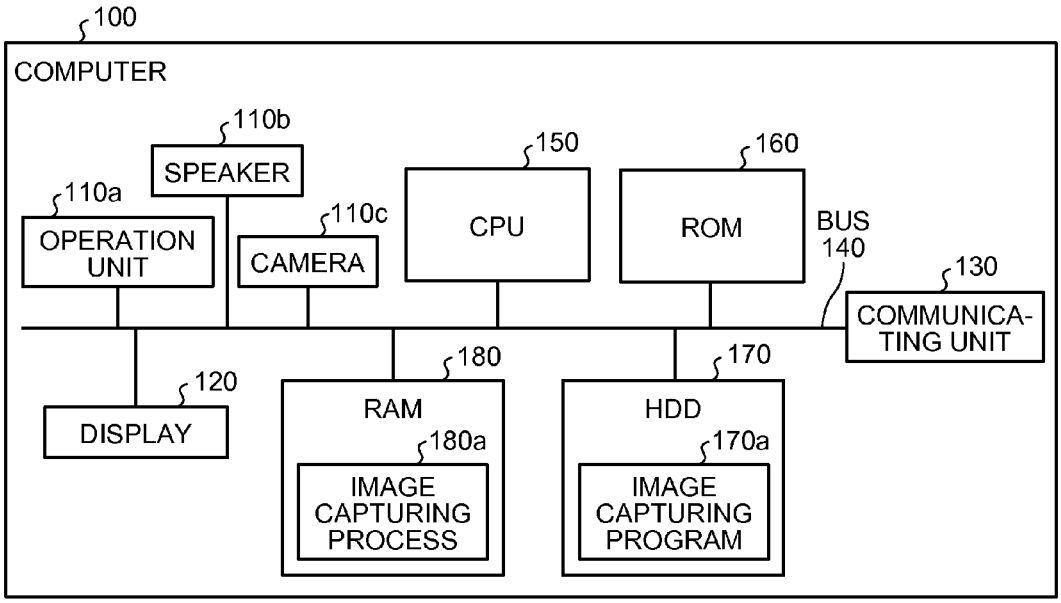
100
COMPUTER
110b
SPEAKER
110a
OPERATION UNIT
110c
CAMERA
150
CPU
160
ROM
BUS
140
130
COMMUNICA-TING UNIT
120
DISPLAY
180
RAM
180a
IMAGE CAPTURING PROCESS
170
HDD
170a
IMAGE CAPTURING PROGRAM

IMAGE CAPTURING METHOD AND IMAGE CAPTURING APPARATUS FOR ILLUMINATING SUBJECT

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority of the prior Japanese Patent Application No. 2013-012688, filed on Jan. 25, 2013, the entire contents of which are incorporated herein by reference.

FIELD

The embodiments discussed herein are related to an image capturing method, an image capturing apparatus, and an image capturing program.

BACKGROUND

Various authentication technologies such as biometric authentication or gesture authentication have been known. In the biometric authentication, for example, there are cases where the authentication rate declines because the similarity between two images declines when the intensities of external light differs between capturing a registered image and capturing a matching image. Disclosed as an example of a technology for reducing the influence of external light is an image processing method for acquiring a difference between an OFF image captured during an OFF state in which the illumination is turned OFF and an ON image captured during an ON state in which the illumination is turned ON. The image processing method aims to acquire an image that does not include external light but illumination light by computing the difference between an OFF image captured with only the external light and an ON image captured with the external light and illumination light.

However, when the external light is strong, the pixel values for the portion illuminated with the external light within the area captured by the camera saturate at the upper boundary, and a phenomenon called saturation is thus produced in which such a portion becomes completely white. Therefore, when the difference between the OFF image and the ON image is simply acquired, the authentication ratio may remain low because the characteristics of the region to be biometrically authenticated are lost due to the saturation.

As an example of a technology for solving saturation, Japanese Laid-open Patent Publication No. 2008-90412, for example, discloses an image generating method for dividing an image capturing process into sub-steps based on the intensities of external light, alternately capturing OFF images and ON images, and integrating differences between respective pairs of the OFF image and ON image. This image generating method aims to acquire an image in which the influence of saturation is reduced by reducing the length of the exposure time during capturing of the images to reduce the amount of incident light and by integrating the captured difference images.

However, such a technology has a disadvantage that the time for capturing images is extended as explained below.

To explain, in the image generation method mentioned above, OFF images and ON images are captured alternatingly. When OFF images and ON images are captured alternatingly, the illumination is switched every time an OFF image or an ON image is to be captured. In other words, the illumination is switched from ON to OFF every time an OFF image is to be captured, and the illumination is switched from

OFF to ON every time an ON image is to be captured. Because images captured during the process of switching the illumination are captured without the illumination not completely turned OFF or completely turned ON, and such images could be a cause for reducing authentication accuracy, it is preferable not to use the images in the authentication. Because capturing operation is withheld until the illumination is switched OFF or ON every time an OFF image or an ON image is to be captured, the image capturing time is extended.

SUMMARY

According to an aspect of an embodiment, an image capturing method is executed by an image capturing apparatus including an illumination that illuminates a subject. The image capturing method includes: continuously generating, using a processor, one or more OFF images in which the subject is captured with the illumination turned OFF, for a first number of times; continuously generating, using the processor, ON images in which the subject is captured with the illumination turned ON, for a second number of times; continuously generating, using the processor, one or more OFF images in which the subject is captured with the illumination turned OFF, for the first number of times; computing, using the processor, a difference image between each of the generated ON images and the OFF image corresponding to the ON image among the generated OFF images; and integrating, using the processor, the computed difference images.

The object and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a block diagram illustrating functional configurations of apparatuses included in a gesture authentication system according to a first embodiment of the present invention;

FIG. **2** is a schematic of an example of an image capturing sequence;

FIG. **3** is a schematic of another example of the image capturing sequence;

FIG. **4** is a schematic of another example of the image capturing sequence;

FIG. **5** is a schematic of another example of the image capturing sequence;

FIG. **6** is a schematic of an example of a relation between time and a variation level;

FIG. **7** is a flowchart illustrating an authenticating process according to the first embodiment;

FIG. **8** is a flowchart illustrating a divisor determining process according to the first embodiment;

FIG. **9** is a flowchart illustrating an image capturing process according to the first embodiment;

FIG. **10** is a block diagram illustrating functional configurations of apparatuses included in a face authentication system according to a second embodiment of the present invention;

FIG. **11** is a flowchart illustrating a registration process according to the second embodiment;

FIG. **12** is a flowchart illustrating an authenticating process according to the second embodiment;

FIG. **13** is a block diagram illustrating functional configurations of apparatuses included in a material determining system according to a third embodiment of the present invention;

FIG. **14** is a schematic of an example of an image capturing sequence;

FIG. **15** is a schematic of an example of information in which an output current is associated with a divisor;

FIG. **16** is a graph illustrating an example of a relation between a wavelength and reflectance of different materials;

FIG. **17** is a flowchart illustrating a determining process according to the third embodiment;

FIG. **18** is a flowchart illustrating a divisor determining process according to the third embodiment;

FIG. **19** is a flowchart illustrating an image capturing process according to the third embodiment;

FIG. **20** is a flowchart illustrating an example of a divisor determining process;

FIG. **21** is a schematic of an example of an image capturing sequence; and

FIG. **22** is a schematic for explaining an example of a computer for executing an image capturing program according to the first to the third embodiments.

DESCRIPTION OF EMBODIMENTS

Preferred embodiments of the present invention will be explained with reference to accompanying drawings. The embodiments are not intended to limit the technology according to the invention in any way. These embodiments may also be combined in any way within an extent not making any process contradictory.

[a] First Embodiment

FIG. **1** is a block diagram illustrating functional configurations of apparatuses included in a gesture authentication system according to a first embodiment of the present invention. This gesture authentication system **10** authenticates a gesture such as a bodily gesture or a hand gesture of a person, by using a difference image between an OFF image captured during an OFF state in which the illumination is turned OFF and an ON image captured during an ON state in which the illumination is turned ON. In the first embodiment, it is assumed that, as an example, the result of a gesture authentication output from an authentication apparatus **12** is used in operating a channel of a television receiver not illustrated. Alternatively, the gesture authentication result may be used as a human-machine interface of a personal computer or the like.

As illustrated in FIG. **1**, the gesture authentication system **10** includes an image capturing apparatus **11** and the authentication apparatus **12**. Illustrated in FIG. **1** is an example in which the image capturing apparatus **11** is provided in singularity to the gesture authentication system **10**. Alternatively, the image capturing apparatus **11** may be provided in plurality.

Configuration of Image Capturing Apparatus **11**

To begin with, a functional configuration of the image capturing apparatus **11** according to the first embodiment will be explained. As illustrated in FIG. **1**, the image capturing apparatus **11** includes a sensor unit **11***a*, an illumination unit **11***b*, an image sensor **11***c*, a communicating unit **11***d*, an image storage unit **11***e*, and an image capturing control unit **11***f*. The image capturing apparatus **11** may also include various functional units provided to a camera, such as an optical lens or an optical filter, in addition to the functional units illustrated in FIG. **1**.

Among these functional units, the sensor unit **11***a* is a device for detecting a user of the television receiver. As a possible implementation of the sensor unit **11***a*, a human detection sensor that detects a person with visible light, infrared, ultrasonic waves, or temperature may be used. The sensor unit **11***a* monitors, for example, a predetermined viewing area, e.g., an area within a radius of 5 meters, from the display surface of the television receiver. When the sensor unit **11***a* detects a user in the viewing area of the television receiver, the sensor unit **11***a* notifies the image capturing control unit **11***f*, which will be described later, of the position of the user in the viewing area.

The illumination unit **11***b* is a light source that emits illuminating light. As a possible implementation of the illumination unit **11***b*, a light emitting diode (LED) emitting visible light, as well as light sources emitting near infrared or infrared, may be used. The illumination unit **11***b* is installed at a position capable of illuminating an authenticated region such as a hand of the user who is in the viewing area that is detected by the sensor unit **11***a*, for example. When the illumination unit **11***b* has directivity, the illumination unit **11***b* may also be provided with a mechanical unit for allowing the direction in which the illuminating light is output to be adjusted depending on the position of the user in the viewing area.

The image sensor **11***c* is a sensor that converts the light incident from a lens not illustrated into an electric signal. As a possible implementation of the image sensor **11***c*, a charge coupled device (CCD) or a complementary metal oxide semiconductor (CMOS) may be used. The image sensor **11***c* is installed at a position allowing the authenticated region such as a hand of the user in the viewing area detected by the sensor unit **11***a* to be imaged, for example. The image sensor **11***c* may also be provided with a mechanical unit for adjusting the angular field of the image capturing apparatus **11** depending on the position where the user is present in the viewing area so that the authenticated region of the user can be imaged on the image sensor **11***c*. An image captured by the image sensor **11***c* is stored in the image storage unit **11***e* by the image capturing control unit **11***f* which will be explained later.

The communicating unit **11***d* is a processing unit that transmits and receives data to and from other apparatuses including the authentication apparatus **12**. As a possible implementation, the communicating unit **11***d* transmits a notification indicating that a user is detected or an image stored in the image storage unit **11***e* to the authentication apparatus **12**, and receives an image capturing instruction from the authentication apparatus **12**. The communicating unit **11***d* may be connected to a communicating unit **12***a* included in the authentication apparatus **12** over a wire, such as a connector or a cabled local area network (LAN), or wirelessly, e.g., over the Bluetooth (registered trademark), infrared communication, or a wireless LAN.

The image storage unit **11***e* is a storage device storing therein images. As an example, the image storage unit **11***e* stores therein an image captured by the image capturing control unit **11***f*. As another example, the image storage unit **11***e* is accessed when an image stored in the image storage unit **11***e* is read before such an image is transferred to the authentication apparatus **12**. An image stored in the image storage unit **11***e* may be deleted after the image is transmitted to the authentication apparatus **12**.

The image capturing control unit **11***f* is a processing unit that controls the illumination unit **11***b* and the image sensor **11***c* to allow an image of a subject to be captured. As a possible implementation, the image capturing control unit **11***f* notifies the authentication apparatus **12** that a user is detected when the sensor unit **11***a* detects a user in the viewing area. When the authentication apparatus **12** receives a notification of a user being detected, the image capturing control unit **11***f*

receives an image capturing instruction from the authentication apparatus **12**, as a response to such a notification. The "image capturing instruction" herein includes image capturing parameters related to an "OFF image" captured in an OFF state in which the illumination is turned OFF, and to an "ON image" captured in an ON state in which the illumination is turned ON. An example of the image capturing parameters includes an exposure time E for which the image sensor **11***c* is exposed to light that is imaged through the lens not illustrated, and a divisor N by which the exposure time E is divided. When such an image capturing instruction is received, the image capturing control unit **11***f* computes a unit exposure time E' representing an exposure time for a single piece of image, by dividing the exposure time E by the divisor N included in the image capturing instruction. After computing the unit exposure time E', the image capturing control unit **11***f* captures N pieces of OFF image and N pieces of ON image.

The image capturing control unit **11***f* captures the OFF images by turning OFF the illumination unit **11***b* before and after capturing N pieces of ON images. For example, after turning OFF the illumination unit **11***b* and capturing N/2 pieces of OFF images, the image capturing control unit **11***f* turns ON the illumination unit **11***b* and captures N pieces of ON images. The image capturing control unit **11***f* then turns OFF the illumination unit **11***b* again, and captures N/2 pieces of OFF images.

FIG. **2** is a schematic of an image capturing sequence. Illustrated as an example in FIG. **2** is an image capturing sequence in an example when the divisor N is "4". As illustrated in FIG. **2**, the image capturing control unit **11***f* keeps the illumination unit **11***b* OFF for a period from time T**0** to time T**2**, and closes the shutter temporarily at time T**1**. The image capturing control unit **11***f* then causes the image storage unit **11***e* to store therein an OFF image a**1** acquired through the exposure over a period "T**0** to T**1**", and to store therein an OFF image a**2** acquired through the exposure over a period "T**1** to T**2**". The image capturing control unit **11***f* then switches the illumination unit **11***b* from OFF to ON at time T**2**. Because completely switching the illumination unit **11***b* from OFF to ON takes a certain length of time, the image capturing control unit **11***f* performs null write to the image storage unit **11***e* for an image acquired through the exposure over a period "T**2** to T**3**", assuming that switching from OFF to ON takes time from time T**2** to time T**3**. Such null write is performed because any image acquired before switching to ON or OFF is completed is not used in the authentication.

The image capturing control unit **11***f* keeps the illumination unit **11***b* ON for a period from time T**3** to time T**6**, and closes the shutter temporarily at time T**4**, time T**5**, and time T**6**. As a result, an ON image b**1** acquired through the exposure over a period "T**3** to T**4**", an ON image b**2** acquired through the exposure over a period "T**4** to T**5**", an ON image b**3** acquired through the exposure over a period "T**5** to T**6**", and an ON image b**4** acquired through the exposure over a period "T**6** to T**7**" are stored in the order listed herein in the image storage unit **11***e*. The image capturing control unit **11***f* then switches the illumination unit **11***b* from ON to OFF at time T**7**. The image capturing control unit **11***f* performs null write to the image storage unit **11***e* for an image acquired through the exposure over a period "T**7** to T**8**". The image capturing control unit **11***f* then keeps the illumination unit **11***b* OFF for a period from time T**8** to time T**10**, and closes the shutter temporarily at time T**9** and time T**10**. In this manner, the image capturing control unit **11***f* stores an ON image a**4** acquired through the exposure over a period "T**9** to T**10**" in the image storage unit **11***e*, after storing an ON image a**3** acquired through the exposure over a period "T**8** to T**9**" in the image storage unit **11***e*.

The OFF images and the ON images stored in the image storage unit **11***e* are sequentially read by the image capturing control unit **11***f*, and transmitted to the authentication apparatus **12** via the communicating unit **11***d*. These OFF images and the ON images may be assigned with identification information such as a frame number in an ascending or descending order of the sequence in which these images are captured, when these images are stored in the image storage unit **11***e* or when these images are transmitted to the authentication apparatus **12**.

By turning OFF the illumination unit **11***b* and capturing N/2 OFF images before and after N ON images are captured, the time and the number of times for null write can be reduced. FIG. **3** is a schematic of an example of an image capturing sequence. Illustrated in FIG. **3** is a sequence in which four OFF images and four ON images are captured alternatingly. As illustrated in FIG. **3**, when OFF images and ON images are captured alternatingly, null write is performed for images for a period "T**1** to T**2**", a period "T**3** to T**4** ", a period "T**5** to T**6**", and a period "T**1** to T**8**", as well as for images for a period "T**9** to T**10**", a period "T**11** to T**12**", period "T**13** to T**14**", and a period "T**15** to T**16**". In other words, when OFF images and ON images are captured alternatingly, null write is performed eight times in total. When the illumination unit **11***b* is turned OFF before and after N pieces of ON images are captured and then N/2 pieces of OFF images are captured, null write is made only twice. Because the image capturing apparatus **11** according to the first embodiment can reduce the time and the number of times for null write, idle time for capturing images can be reduced.

As the image capturing control unit **11***f*, various types of integrated circuits or electronic circuits may be used. An example of an integrated circuit includes an application specific integrated circuit (ASIC). Examples of an electronic circuit include a central processing unit (CPU) and a microprocessing unit (MPU).

As the image storage unit **11***e*, a semiconductor memory device or a storage device may be used. Examples of the semiconductor memory device include a video random access memory (VRAM), a random access memory (RAM), and a flash memory. Examples of the storage device include storage devices such as a hard disk or an optical disk.

Configuration of Authentication Apparatus **12**

A functional configuration of the authentication apparatus **12** according to the first embodiment will now be explained. As illustrated in FIG. **1**, the authentication apparatus **12** includes the communicating unit **12***a*, a storage unit **12***b*, an image capturing instructing unit **12***c*, a determining unit **12***d*, a computing unit **12***e*, an integrating unit **12***f*, and an authenticating unit **12***g*.

Among these units, the communicating unit **12***a* is a processing unit that transmits and receives data to and from other apparatuses including the image capturing apparatus **11**. As a possible implementation, the communicating unit **12***a* receives a notification indicating that a user is detected, OFF images, and ON images from the image capturing apparatus **11**, and transmits an image capturing instruction. The communicating unit **12***a* may be connected to the communicating unit **11***d* in the image capturing apparatus **11** over a wire, such as a connector or a cabled LAN, or wirelessly, e.g., over the Bluetooth (registered trademark), infrared communication, or a wireless LAN.

The storage unit **12***b* is a storage device storing therein various types of information. As a possible implementation,

the storage unit **12***b* stores therein OFF images, ON images, a difference image representing a difference between an OFF image and an ON image, an integrated image in which difference images are integrated, and a gesture pattern image that is matched against the integrated image. As an example, when OFF images or ON images are received from the image capturing apparatus **11**, the storage unit **12***b* stores therein the OFF images or the ON images. As another example, when a difference between an OFF image and an ON image is computed, the storage unit **12***b* stores therein the difference image. As still another example, the storage unit **12***b* stores therein an integrated image in which a plurality of difference images are integrated. As another example, when a gesture authentication is to be executed, the storage unit **12***b* is accessed by the authenticating unit **12***g*, which will be described later, so as to allow a reference to an integrated image and a gesture pattern image against which the integrated image is matched.

The image capturing instructing unit **12***c* is a processing unit that gives an image capturing instruction to the image capturing apparatus **11**. As a possible implementation, when a notification indicating that a user is in the viewing area is received from the sensor unit **11***a* in the image capturing apparatus **11**, the image capturing instructing unit **12***c* causes the determining unit **12***d*, which will be described later, to determine a divisor N, which is to be included in the image capturing parameters. The image capturing instructing unit **12***c* then transmits an image capturing instruction containing the image capturing parameters including the divisor N determined by the determining unit **12***d* and the exposure time E to the image capturing apparatus **11**. The image capturing instructing unit **12***c* then stores OFF images and ON images received from the image capturing apparatus **11** in the storage unit **12***b*. When N pieces of OFF images and N pieces of ON images are stored in the storage unit **12***b*, the image capturing instructing unit **12***c* gives an instruction for computing a difference image to the computing unit **12***e*, which will be described later.

The determining unit **12***d* is a processing unit that determines the divisor N based on the intensity of external light. As a possible implementation, the determining unit **12***d* sets an initial value N_0 that is preferably applied in an environment without any external light to the divisor N, and sets the unit exposure time E' to E/N that is computed from the exposure time E and the divisor N, before causing the image capturing apparatus **11** to capture a predetermined number of ON images. Because the ON images thus captured by the image capturing apparatus **11** are used for establishing the divisor N, the number of ON images thus captured does not necessarily need to be in plurality, as long as least one ON image is captured. Furthermore, because it is intended herein to explore the optimal divisor by setting the initial divisor small and gradually increasing the divisor, it is assumed herein that "1" is set to the initial value N_0, as an example. However, it is also possible to explore the optimal divisor by initially setting a divisor expected to be the largest, and by gradually reducing the divisor.

After causing the image capturing apparatus **11** to capture the ON images, the determining unit **12***d* computes an external light evaluation value Ex, serving as an index for the intensity of external light, from the ON images. As examples of the method for computing the external light evaluation value Ex, various calculations may be used depending on characteristics or the like used in the authentication. For example, a small area C may be set at the center of the ON image, and a ratio of pixels with saturation with respect to the small area C may be computed as the external light evaluation value Ex. The optimal size or the position of the small area C varies depending on the subject assumed or how the subject is illuminated. For example, the small area C is established correspondingly to an environment in which the images are captured, e.g., considering whether such images are captured in a condition resulting in the highest luminance at the center of the image or in a condition resulting in a high luminance in a specific area of the image. Furthermore, an average luminance, a maximum luminance, a minimum luminance, a median luminance, or a most frequent luminance may be used as an index, instead of the saturation pixel ratio serving as the index.

The determining unit **12***d* then determines if the external light evaluation value Lx is lower than a predetermined threshold Th. If the external light evaluation value is lower than the predetermined threshold, it can be assumed that saturation is not likely to be produced on images when the images are captured based on the unit exposure time E'. In such a case, the determining unit **12***d* determines the divisor N used previously as the divisor N. If the external light evaluation value Ex is equal to or higher than the predetermined threshold Th, it can be assumed that saturation is likely to be produced on ON images when the images are captured with the unit exposure time E'. In such a case, the determining unit **12***d* updates the divisor N to a value larger than the previous value, e.g., a value twice the previous divisor. The determining unit **12***d* repeats the process of updating the divisor, setting a unit exposure time E', and computing the external light evaluation value Ex, until the external light evaluation value Ex reaches a value lower than the threshold Th. The divisor N thus determined is output to the image capturing instructing unit **12***c*.

The computing unit **12***e* is a processing unit that computes a difference image using an OFF image and an ON image stored in the storage unit **12***b*. As a possible implementation, when an instruction for computing a difference image is received from the image capturing instructing unit **12***c*, the computing unit **12***e* reads N pieces of OFF images and N pieces of ON images stored in the storage unit **12***b*. The computing unit **12***e* then determines N pairs of an OFF image and an ON image from the OFF images and the N pieces of ON images read from the storage unit **12***b*. It is preferable for such images to be paired into N pairs in a manner so that the sum of differences between the time at which the OFF images are captured and the time at which the respective ON images are captured becomes the smallest. For example, the computing unit **12***e* pairs an OFF image and an ON image each of which is captured at the earliest timing, among the N pieces of OFF images and the N pieces of ON images. The computing unit **12***e* then computes the difference between the pixel values in the OFF image and the respective pixel values in the ON image in each of these pairs. In this manner, the computing unit **12***e* computes N pieces of difference images. The computing unit **12***e* then stores the N pieces of difference images in the storage unit **12***b*.

To explain using the example illustrated in FIG. **2**, the computing unit **12***e* establishes four pairs by pairing the OFF image a**2** and the ON image b**2**, pairing the OFF image a**2** and the ON image b**2**, pairing the OFF image a**3** and the ON image b**3**, and pairing the OFF image a**4** and the ON image b**4**. The computing unit **12***e* then computes a difference image ab**1** by computing pixel value differences between the pixels in the OFF image a**1** and those in the ON image b**1**. In the same manner, the computing unit **12***e* computes a difference image ab**2** from the OFF image a**2** and the ON image b**2**, computes a difference image ab**3** from the OFF image a**3** and the ON image b**3**, and computes a difference image ab**4** from the OFF

image a**4** and the ON image b**4**. By computing the difference images ab**1** to ab**4** in the manner described above, the difference in time between when the ON image is captured and when the OFF image is captured can be kept to two unit exposure times E' at a maximum.

When used is the image capturing sequence in which the illumination unit **11***b* is turned OFF and N/2 pieces of OFF images are captured before and after N pieces of ON images are captured, the influence of time-dependent variations in the position of the subject or the intensity of external light can be reduced, compared with when another image capturing sequence is used.

FIGS. **4** and **5** are schematics of examples of an image capturing sequence. FIG. **6** is a schematic of an example of a relation between time and a variation level. Illustrated in FIG. **4** is an image capturing sequence in which an ON image is captured continuously for four times, and then OFF image is captured continuously for four times. Illustrated in FIG. **5** is an image capturing sequence that is the same as that illustrated in FIG. **2**. FIG. **6** schematically illustrates a degree by which the position of the subject or the intensity of external light changes from time t**1** to time t**8**, each at which an image is captured, and reference time t positioned at the center of the time while which these eight images are captured.

Because ON images β**1** to β**4** illustrated in FIG. **4** are captured at "t**1**", "t**2**", "t**3**", and "t**4**", respectively, the degree of change from the reference time t becomes "+4", "+3", "+2", and "+1", as illustrated in FIG. **6**. Therefore, the total degree of change for the ON images β**1** to β**4** reaches "**10**". Because OFF images α**1** to α**4** are captured at "t**5**", "t**6**", "t**7**", and "t**8**", respectively, the degree of change from the reference time becomes "−4", "−3", "−2", and "−1", respectively, as illustrated in FIG. **6**. Therefore, the total degree of change for the OFF images α**1** to α**4** also reaches "10". Therefore, when difference images αβ**1** to αβ**4** are computed, the degree of change results in "20".

By contrast, because the OFF images a**1** to a**4** illustrated in FIG. **5** are captured at "t**1**", "t**2**", "t**7**", and "t**8**", respectively, the degree of change from the reference time t becomes "+4", "+3", "−3", and "−4", as illustrated in FIG. **6**. Therefore, the total degree of change for the OFF images a**1** to a**4** can be suppressed to "0". Because the ON images b**1** to b**4** are captured at "t**3**", "t**4**", "t**5**", and "t**6**", respectively, the degree of change from the reference time t becomes "+2", "+1", "−2", and "−", respectively, as illustrated in FIG. **6**. Therefore, the total degree of change for the ON images b**1** to b**4** can also be suppressed to "0". Therefore, when difference images αβ**1** to αβ**4** are computed, the degree of change can be suppressed to "0".

In particular, when used is an image capturing sequence in which the illumination ON images are positioned at the center, the illumination ON images can be captured continuously. Because the illumination ON images include external light as well as the light from the illumination itself, such images have higher luminance than that in the illumination OFF images. Therefore, illumination ON images are more affected by variations in the subject or the external light than the illumination OFF images. By capturing such illumination ON images continuously, the influence of such variations can be further reduced.

Based on the reason described above, it can be understood that, when the image capturing sequence illustrated in FIG. **5** is used, the influence of time-dependent variations in the position of the subject or the intensity of external light can be reduced, compared with when the image capturing sequence illustrated in FIG. **4** is used.

The integrating unit **12***f* is a processing unit that integrates difference images. As a possible implementation, when N pieces of difference images are computed by the computing unit **12***e*, the integrating unit **12***f* reads the N pieces of difference images from the storage unit **12***b*, and acquires the sum of the pixel values for each pixel of the N pieces of difference images read from the storage unit **12***b*. In this manner, a single piece of integrated image can be generated from the N pieces of difference images. Because the difference between each of the ON images and each of the OFF images has been computed, the integrated image thus generated will be an image in which the influence of external light is suppressed, represented as if the images were captured only with the illumination from the illumination unit **11***b*. Furthermore, because difference images captured based on a divided exposure time are integrated, images can be captured while keeping the exposure time short. As a result, saturation is suppressed in the resultant integrated image, even when strong external light is present. Therefore, it is possible to acquire an image in which the authenticated region of the user who is in the viewing area of the television receiver is captured appropriately.

The authenticating unit **12***g* is a processing unit that authenticates a gesture of a subject using an integrated image generated by the integrating unit **12***f*. As a possible implementation, the authenticating unit **12***g* extracts an image portion that is similar to the shape of a hand from the integrated image as an image to be authenticated, by applying image processing such as edge detection or skin color detection to the integrated image. The authenticating unit **12***g* then executes an image matching process such as pattern matching between the image to be authenticated extracted via the image processing and the gesture pattern image stored in the storage unit **12***b*. An example of the gesture pattern image includes an image representing a pattern of the shape of a hand rising fingers in the number corresponding to a channel number. For example, the authenticating unit **12***g* computes the similarity between each of the gesture pattern images and the image to be authenticated. The authenticating unit **12***g* then determines if there is any gesture pattern image with a similarity to the authenticated image higher than a predetermined threshold. If there is any pattern image with a similarity higher than the threshold, the authenticating unit **12***g* outputs a gesture corresponding to the pattern image or a command corresponding to the gesture to the television receiver. In this manner, the television receiver is caused to execute a command corresponding to the gesture, that is, to change the channel, in the example mentioned above.

As the image capturing instructing unit **12***c*, the determining unit **12***d*, the computing unit **12***e*, the integrating unit **12***f*, and the authenticating unit **12***g*, various types of integrated circuits or electronic circuits may be used. An example of an integrated circuit includes an ASIC. Examples of an electronic circuit include a CPU or an MPU.

As the storage unit **12***b*, a semiconductor memory device or a storage device may be used. Examples of the semiconductor memory device include a VRAM, a PAM, and a flash memory. Examples of the storage device include storage devices such as a hard disk or an optical disk.

Sequence of Processes

The sequence of processes performed by the gesture authentication system **10** according to the first embodiment will now be explained. In this section, (1) an authenticating process performed by the gesture authentication system **10** will be explained to begin with, and (2) a divisor determining process and (3) an image capturing process included in the authenticating process will then be explained in detail.

(1) Authenticating Process

FIG. **7** is a flowchart illustrating an authenticating process according to the first embodiment. This authenticating process is initiated when the sensor unit **11***a* detects a user in the viewing area of the television receiver. As illustrated in FIG. **7**, when the sensor unit **11***a* detects a user in the viewing area (Step S**101**), the image capturing control unit **11***f* notifies the authentication apparatus **12** that a user is detected in the viewing area (Step S**102**).

In response, the determining unit **12***d* in the authentication apparatus **12** executes a "divisor determining process" for determining the divisor N by which the exposure time E is divided (Step S**103**). The image capturing instructing unit **12***c* then sends an image capturing instruction containing image capturing parameters including the divisor N determined by the determining unit **12***d* to the authentication apparatus **12** (Step S**104**).

The image capturing control unit **11***f* receiving the image capturing instruction then executes an "image capturing process" in which N pieces of OFF images and N pieces of ON images are captured, in the order of N/2 pieces of OFF images, N pieces of ON images, and N/2 pieces of OFF images (Step S**105**). The image capturing control unit **11***f* then transfers the N pieces of OFF images and the N pieces of ON images to the authentication apparatus **12** via the communicating unit **11***d* (Step S**106**).

The image capturing instructing unit **12***c* in the authentication apparatus **12** then stores the N pieces of OFF images and the N pieces of ON images in the storage unit **12***b* (Step S**107**). The computing unit **12***e* then determines N pairs of an OFF image and an ON image, and computes N pieces of difference images from the respective pairs of an OFF image and an ON image (Step S**108**). The computing unit **12***e* then stores the N pieces of difference images computed at Step S**108** in the storage unit **12***b* (Step S**109**).

The integrating unit **12***f* then generates a single piece of integrated image from the N pieces of difference images, by acquiring the sum of the pixel values across the N pieces of difference images stored in the storage unit **12***b* (Step S**110**). The integrating unit **12***f* then stores the integrated image generated at Step S**110** in the storage unit **12***b* (Step S**111**).

The authenticating unit **12***g* then computes a similarity between an image of the authenticated region detected from the integrated image stored in the storage unit **12***b* at Step S**111** and each of the gesture pattern images stored in the storage unit **12***b* (Step S**112**).

If any pattern image has a similarity higher than the predetermined threshold (Yes at Step S**113**), the authenticating unit **12***g* executes the following process. In other words, the authenticating unit **12***g* outputs a gesture corresponding to the pattern image or a command corresponding to the gesture to the television receiver (Step S**114**), and the process is ended. If no pattern image has a similarity higher than the predetermined threshold (No at Step S**113**), the process is ended at this point.

(2) Divisor Determining Process

FIG. **8** is a flowchart illustrating a divisor determining process according to the first embodiment. This process is initiated when the process at Step S**102** is executed in the authenticating process illustrated in FIG. **7**, that is, when a notification of a user detection is received from the image capturing apparatus **11**.

As illustrated in FIG. **8**, the determining unit **12***d* sets the initial value N_0 preferably applied in an environment without any external light to the divisor N (Step S**201**). The determining unit **12***d* then sets the unit exposure time E' to E/N computed from the exposure time E and the divisor N (Step S**202**).

The determining unit **12***d* then causes the image capturing apparatus **11** to capture a predetermined number of ON images based on the unit exposure time E' (Step S**203**). The determining unit **12***d* then computes an external light evaluation value Ex serving as an index for the intensity of external light from the ON images captured at Step S**203** (Step S**204**). The determining unit **12***d* then determines if the external light evaluation value Ex is lower than a predetermined threshold Th (Step S**205**).

If the external light evaluation value Ex is equal to or higher than the predetermined threshold Th (No at Step S**205**), it can be assumed that saturation is likely to be produced on images when the images are captured based on the unit exposure time E'. In such a case, the determining unit **12***d* updates the divisor N to a value larger than the previous value, e.g., a value twice the previous divisor (Step S**206**). The system control then goes to Step S**202**, and the determining unit **12***d* repeats the process of updating the divisor, setting a unit exposure time E', causing the image capturing apparatus **11** to capture ON images, and computing the external light evaluation value Ex, until the external light evaluation value Ex reaches a value lower than the threshold Th.

If the external light evaluation value is lower than the predetermined threshold (Yes at Step S**205**), it can be assumed that saturation is not likely to be produced on ON images when the images are captured based on the unit exposure time E'. In such a case, the determining unit **12***d* outputs the divisor N used at Step S**201** or Step S**206** to the image capturing instructing unit **12***c* (Step S**207**), and the process is ended.

(3) Image Capturing Process

FIG. **9** is a flowchart illustrating an image capturing process according to the first embodiment. The image capturing process is initiated when the process at Step S**104** is executed in the authenticating process illustrated in FIG. **7**, that is, when an image capturing instruction is received from the authentication apparatus **12**.

As illustrated in FIG. **9**, if an image capturing instruction containing the exposure time E, the divisor N, and the like is received from the authentication apparatus **12**, the image capturing control unit **11***f* computes the unit exposure time E' representing an exposure time for a single piece of image, by dividing the exposure time E by the divisor N (Step S**301**).

The image capturing control unit **11***f* then turns OFF the illumination unit **11***b*, and captures N/2 pieces of OFF images (Step S**302**). The image capturing control unit **11***f* then turns ON the illumination unit **11***b*, and captures N pieces of ON images (Step S**303**). The image capturing control unit **11***f* then turns OFF the illumination unit **11***b*, and captures N/2 pieces of OFF images (Step S**304**).

Finally, the image capturing control unit **11***f* stores the N pieces of OFF images and the N pieces of ON images captured at Steps S**302** to S**304** in the image storage unit **11***e* (Step S**305**), and the process is ended.

Advantageous Effects Achieved by First Embodiment

As described above, the gesture authentication system **10** according to the first embodiment turns OFF the illumination unit **11***b* and captures OFF images before and after N pieces of ON images are captured. Therefore, in the gesture authentication system **10** according to the first embodiment, because the frequency at which the illumination is switched from ON to OFF and switched from OFF to ON can be reduced, the frequency of and the time for null write can be reduced. As a result, idle time for capturing images can be reduced. Therefore, the gesture authentication system **10** according to the first embodiment can reduce the image capturing time.

Furthermore, in the gesture authentication system **10** according to the first embodiment, the authentication apparatus **12** executes the process of capturing ON images and determining the divisor through trial-and-error, the process of computing the difference between an OFF image and an ON image, the process of integrating the difference images, and the like. Therefore, the gesture authentication system **10** according to the first embodiment can simplify the functional configuration of the image capturing apparatus **11**. There are more advantageous effects that can be achieved by simplifying the image capturing apparatus **11**. For example, in a possible configuration in which a gesture authentication is executed, the authentication apparatus **12** may be built into a fixed place, e.g., near the television receiver or in the television receiver, but the place where the image capturing apparatus **11** is installed may be changed depending on how the image capturing apparatus **11** is used by the user. Furthermore, another possible configuration of the system may include one authentication apparatus **12** and a plurality of image capturing apparatuses **11**. When such a system configuration is used, the entire cost can be reduced when the configuration of the image capturing apparatus **11** is simplified.

Furthermore, in the gesture authentication system **10** according to the first embodiment, OFF images that are divided into equal groups are captured before and after the ON images are captured, an ON image and an OFF image at the same order are in the order of the time at which these images are captured, and difference images are computed for each of these pairs. Therefore, for example, the influence of variations such as positional changes, e.g., those of when the hand of the subject gradually moves down, changes in the external light intensity due to a blocking object, and the like can be evenly allocated to the OFF image and the ON image for which a difference is computed. Therefore, difference images that are less affected by such variations can be computed stably.

Furthermore, because the ON images are captured continuously at the center of the image capturing sequence, the influence of the variations in the external light and the subject can be reduced. This is because an ON image has higher luminance, an ON image is more influenced by such variations than an OFF image. Therefore, by capturing the ON images continuously at the center of the image capturing sequence, the influence of such variations can be further reduced.

Furthermore, in the gesture authentication system **10** according to the first embodiment, because an OFF image and an ON image are captured an even number of times, redundant OFF images and ON images not used in computing a difference image are not captured. Therefore, the image capturing time can be reduced.

Furthermore, in the gesture authentication system **10** according to the first embodiment, because the image capturing time is reduced, extension of time in which the images are captured can be suppressed even when used is an image sensor capturing images at a low rate and a long interval. Because an inexpensive image sensor can be used, costs can be reduced.

[b] Second Embodiment

Explained in the first embodiment is an example in which the authentication apparatus **12** is caused to generate difference images and an integrated image. However, it is not necessarily need to be the authentication apparatus **12** that generates difference images and an integrated image. Furthermore, explained in the first embodiment is an example in which the image capturing apparatus **11** is caused to capture the images to be used in the gesture authentication, but the image capturing apparatus **11** may also capture images to be used in another type of authentication or determination. Therefore, explained in a second embodiment of the present invention is an example in which an image capturing apparatus **21** is caused to capture OFF images and ON images of the face of a person who is a subject, to generate difference images and an integrated image, and an authentication apparatus **22** is caused to execute a face authentication using the integrated image.

Configuration of Face Authentication System

FIG. **10** is a block diagram illustrating functional configurations of apparatuses included in a face authentication system according to the second embodiment. This face authentication system **20** illustrated in FIG. **10** performs a face authentication by matching an integrated image generated from OFF images and ON images in which the face of a person is captured against a registered image that is a pre-registered integrated image of the face of a person based upon which authentication is determined to be successful when the system performs the authentication. In the following description of the second embodiment, it is assumed that the face authentication is used in controlling an entry and exit of someone into and from a gate installed in a facility or at the boundary of a room or a booth of a facility.

As illustrated in FIG. **10**, the face authentication system **20** includes the image capturing apparatus **21** and the authentication apparatus **22**. Among these apparatuses, the image capturing apparatus **21** is installed at a position allowing the face of a person passing through a gate to be captured in the angle of view of the image capturing apparatus **21**, as an example, so that an image of the face of a person passing through the gate can be captured. As an example, the authentication apparatus **22** may be implemented as a server connected to a plurality of the image capturing apparatuses **21**. Alternatively, a function for performing the face authentication may be incorporated into the image capturing apparatus **21** so that face authentication can be performed on standalone basis.

Configuration of Image Capturing Apparatus **21**

To begin with, a functional configuration of the image capturing apparatus **21** according to the second embodiment will be explained. Comparing with the image capturing apparatus **11** illustrated in FIG. **1**, the image capturing apparatus **21** illustrated in FIG. **10** includes the following functional units, instead of the sensor unit **11***a*, the illumination unit **11***b*, the image sensor **11***c*, the communicating unit **11***d*, the image storage unit **11***e*, and the image capturing control unit **11***f*. In other words, the image capturing apparatus **21** includes a sensor unit **21***a*, an illumination unit **21***b*, an image sensor **21***c*, a communicating unit **21***d*, an image storage unit **21***e*, and an image capturing control unit **21***f*.

Because the sensor unit **21***a*, the illumination unit **21***b*, the image sensor **21***c*, the communicating unit **21***d*, the image storage unit **21***e*, the image capturing control unit **21***f*, a determining unit **21***g*, a computing unit **21***h*, and an integrating unit **21***j* have basic functions that are the same as those of the respective functional units illustrated in FIG. **1**, only the differences are explained hereunder.

Among these units, the sensor unit **21***a* is different from the sensor unit **11***a* illustrated in FIG. **1** in that the sensor unit **21***a* detects a user approaching the gate. Therefore, the sensor unit **21***a* monitors an area where people pass through the gate, e.g., a radius of 1 meter from the gate, as an example. When the sensor unit **21***a* detects a user passing through such a pass-through area, the sensor unit **21***a* notifies the image capturing

control unit **21***f*, which will be described later, of entry of the user into the gate pass-through area.

The illumination unit **21***b* is different from the illumination unit **11***b* illustrated in FIG. **1** in that the illumination unit **21***b* illuminates the face of a user approaching the gate. Therefore, the illumination unit **21***b* is installed at a position capable of illuminating the authenticated region of the user, e.g., the face of the user, who is in the pass-through area of the gate detected by the sensor unit **21***a*. When the illumination unit **21***b* has directivity, the illumination unit **21***b* may also be provided with a mechanical unit for allowing the direction in which the illuminating light is output to be adjusted depending on the position of the user in the pass-through area of the gate.

The image sensor **21***c* is different from the image sensor **11***c* illustrated in FIG. **1** in that the image sensor **21***c* is installed at a position enabling the face of the user who is in the pass-through area of the gate to be imaged on a lens not illustrated. The image sensor **21***c* may be provided with a mechanical unit for adjusting the angular field of the image capturing apparatus **21** depending on the position where the user is present in the pass-through area of the gate so as to allow the authenticated region of the use to be imaged on the image sensor **21***c*. The image capturing control unit **21***f*, which will be described later, stores the image captured by the image sensor **21***c* in the image storage unit **21***e*.

The communicating unit **21***d* is different from the communicating unit **11***d* illustrated in FIG. **1** in that the communicating unit **21***d* transmits and receives different types of data to and from other apparatuses including the authentication apparatus **22**. For example, the communicating unit **21***d* transmits a notification of a user entering the pass-through area of the gate or an integrated image to the authentication apparatus **22**. The communicating unit **21***d* also receives an image capturing ending instruction for ending capturing images of the face of the user who have entered the pass-through area of the gate, or a registered image generating instruction for generating a registered image.

The image storage unit **21***e* is different from the image storage unit **11***e* illustrated in FIG. **1** in that the image storage unit **21***e* stores therein different types of data. As mentioned earlier, in the second embodiment, the image capturing apparatus **21** starts capturing OFF images and ON images, and executes calculations of the difference images and generation of the integrated image. Therefore, in the image storage unit **21***e* stores therein difference images and an integrated image, in addition to the original images such as OFF images and ON images received from the image sensor **21***c*.

The image capturing control unit **21***f* is different from the image capturing control unit **11***f* illustrated in FIG. **1** in that the image capturing process is triggered differently. In other words, because the authentication apparatus **22** illustrated in FIG. **10** performs a face authentication, not the gesture authentication executed in the authentication apparatus **12** illustrated in FIG. **1**, the image capturing control unit **21***f* executes the image capturing process, which is executed by the image capturing control unit **11***f* illustrated in FIG. **1**, twice, once at a stage registering the face of a person permitted to go through the gate, and another time at a stage generating the face of a user entering gate.

Furthermore, the image capturing apparatus **21** illustrated in FIG. **10** further includes the determining unit **21***g*, the computing unit **21***h*, and the integrating unit **21***j*, as functional units not illustrated in FIG. **1**. The determining unit **21***g*, the computing unit **21***h*, and the integrating unit **21***j* are different from the determining unit **12***d*, the computing unit **12***e*, and the integrating unit **12***f* included in the authentication apparatus **12** illustrated in FIG. **1** in that these functional units are provided to the apparatus capturing images. In addition, the determining unit **21***g*, the computing unit **21***h*, and the integrating unit **21***j* are different in performing the process at two stages, in the same manner as the process performed by the image capturing control unit **21***f*.

Configuration of Authentication Apparatus **22**

A functional configuration of the authentication apparatus **22** according to the second embodiment will now be explained. The authentication apparatus **22** illustrated in FIG. **10** includes a communicating unit **22***a* and a storage unit **22***b*, instead of the communicating unit **12***a* and the storage unit **12***b* provided to the authentication apparatus **12** illustrated in FIG. **1**.

Because the communicating unit **22***a* and the storage unit **22***b* have basic functions that are the same as those of the corresponding functional units illustrated in FIG. **1**, only the differences are explained hereunder.

The communicating unit **22***a* is different from the communicating unit **12***a* illustrated in FIG. **1** in that the communicating unit **22***a* transmits and receives different types of data to and from other apparatuses including the image capturing apparatus **21**. For example, the communicating unit **22***a* transmits an image capturing ending instruction and a registered image generating instruction to the image capturing apparatus **21**. The communicating unit **22***a* also receives an integrated image and a notification of a user entering the pass-through area of the gate from the image capturing apparatus **21**.

The storage unit **22***b* is different from the storage unit **12***b* illustrated in FIG. **1** in that the storage unit **22***b* stores therein different types of data. In other words, because, in the second embodiment, the image capturing apparatus **21** not only captures OFF images and ON images, but also performs computation of difference images and generation of an integrated image, only the integrated image is stored in the storage unit **22***b*, without storing therein OFF images, ON images, and difference images. For example, when the sensor unit **21***a* detects a user entering the pass-through area of the gate, the storage unit **22***b* stores therein a registered image against which the integrated image of the user generated by the image capturing apparatus **21** is compared. Explained herein is an example in which stored as a registered image is an integrated image of a permitted person who is permitted to make an entry or exit through the gate by the administrator of the face authentication system **20**, as well as characterizing quantities extracted from the integrated image. However, alternatively, only one of the integrated image or the characterizing quantities of the permitted person may also be stored.

Furthermore, the authentication apparatus **22** illustrated in FIG. **10** includes a receiving unit **22***g*, an authenticating unit **22***h*, and a retry control unit **22***j*, as functional units not illustrated in FIG. **1**.

The receiving unit **22***g* is a processing unit that receives an instruction for generating a registered image. As a possible implementation of the receiving unit **22***g*, various types of user interface such as a keyboard or a touch panel can be used. For example, the receiving unit **22***g* receives an instruction for generating a registered image of a permitted person who is permitted to make an entry or exit through the gate from the administrator of the face authentication system **20**, and notifies the image capturing apparatus **21** of the instruction for generating the registered image. In this manner, the image capturing apparatus **21** is caused to capture the OFF images and the ON images of the face of a person whose registered image is to be generated, to compute difference images, and

to generate an integrated image. The receiving unit **22***g* may also be independently implemented outside of the authentication apparatus **22**.

The authenticating unit **22***h* is a processing unit that performs a face authentication of a subject using an integrated image of a user received from the image capturing apparatus **21** and a registered image of a permitted person stored in the storage unit **22***b*. As a possible implementation, the authenticating unit **22***h* detects an image of a portion corresponding to the face by executing template matching to an integrated image. The authenticating unit **22***h* extracts geometric characteristics such as the shape or the size of a part of the face, such as eyes, a nose, a mouth, and ears, from the image corresponding to the face portion detected by the template matching as characterizing quantities. The authenticating unit **22***h* then computes a similarity S between each of the registered images stored in the storage unit **22***b* and characterizing quantities. The authenticating unit **22***h* determines that the authentication is successful if there is any registered image resulting in a similarity S higher than the predetermined threshold. In such a case, it is not necessary to retry the authentication. Therefore, the authenticating unit **22***h* notifies the image capturing apparatus **21** of an image capturing ending instruction, and outputs a notification of the successful authentication to a device unlocking the door, for example. As a result, the user having entered the pass-through area of the gate is permitted to enter or exit. By contrast, if there is only some registered image resulting in a similarity S less than the predetermined threshold, the authenticating unit **22***h* determines that the authentication has failed. In such a case, the retry control unit **22***j*, which will be described later, is caused to determine if the authentication has been retried for a certain number of times. The threshold compared with the similarity S can be specified in any way. For example, the threshold can be lowered when it is preferable to reduce the false rejection rate, and can be raised when it is preferable to reduce the false acceptance rate.

The retry control unit **22***j* is a processing unit that controls retries of the face authentication. As a possible implementation, the retry control unit **22***j* initializes a retry count R recorded in an internal memory not illustrated to zero when a user entering the pass-through area of the gate is detected. The retry control unit **22***j* then increments the retry count R when the authenticating unit **22***h* determines that the authentication has failed, and determines if the retry count R is equal to or higher than the predetermined threshold. If the retry count R is lower than the predetermined threshold, the retry control unit **22***j* permits an authentication retry. When an authentication retry is permitted in the manner described above, the retry control unit **22***j* causes the authenticating unit **22***h* to perform a series of the processes including extracting characterizing quantities from an integrated image of the user, computing a similarity with the registered images, and determining if there is any registered image resulting in a similarity equal to or higher than the threshold. If the retry count is equal to or higher than the threshold, the retry control unit **22***j* does not permit any further retry. In such a case, because it is no longer necessary to generate an integrated image of the user, the retry control unit **22***j* notifies the image capturing apparatus **21** of an image capturing ending instruction, and outputs a notification of the authentication failure to the image capturing apparatus **21**. The threshold compared with the retry count B can be specified in any way. For example, the threshold can be raised when it is preferable to reduce the false rejection rate, and can be lowered when it is preferable to reduce the false acceptance rate.

Sequence of Processes

Processes performed by the face authentication system **20** according to the second embodiment will now be explained. Explained hereunder are (1) a registration process for generating and storing a registered image and (2) an authenticating process performed by the face authentication system **20**. The divisor determining process and the image capturing process included in the registration process and the authenticating process are the same as those according to the first embodiment. Therefore, explanations thereof are omitted herein.

(1) Registration Process

FIG. **11** is a flowchart illustrating a registration process according to the second embodiment. This registration process is initiated when the authentication apparatus **22** receives an instruction for generating a registered image from the administrator.

As illustrated in FIG. **11**, when an instruction for generating a registered image is received (Step S**401**), the receiving unit **22***g* notifies the image capturing apparatus **21** of the instruction for generating a registered image (Step S**402**).

In response, the determining unit **21***g* in the image capturing apparatus **21** executes the "divisor determining process" for determining the divisor N by which the exposure time E is divided (Step S**403**). At Step S**403**, the determining unit **21***g* can execute the same process as that explained in the first embodiment (see FIG. **8**).

The image capturing control unit **21***f* then executes the following process using the image capturing parameters including the divisor N determined by the determining unit **21***g*. In other words, the image capturing control unit **21***f* executes the "image capturing process" in which N pieces of OFF images and N pieces of ON images are captured in the order of N/2 pieces of OFF images, N pieces of ON images, and N/2 pieces of OFF images (Step S**404**). At Step S**404**, the image capturing control unit **21***f* can execute the same process as that explained in the first embodiment (see FIG. **9**).

The computing unit **21***h* then determines N pairs of an OFF image and an ON image, and computes N pieces of difference images from the respective pairs of an OFF image and an ON image (Step S**405**). The computing unit **21***h* then stores the N pieces of difference images computed at Step S**405** in the image storage unit **21***e* (Step S**406**).

The integrating unit **21***j* then generates a single piece of integrated image from the N pieces of difference images, by acquiring the sum of the pixel values across the N pieces of difference images stored in the image storage unit **21***e* (Step S**407**). The integrating unit **21***j* then stores the integrated image generated at Step S**407** in the image storage unit **21***e* (Step S**408**). The image capturing apparatus **21** then transfers the integrated image to the authentication apparatus **22** via the communicating unit **21***d* (Step S**409**).

The authenticating unit **22***h* then stores the integrated image in the storage unit **22***b* as a registered image (Step S**410**). The authenticating unit **22***h* extracts geometric characteristics such as the shape or the size of a part of the face, e.g., eyes, a nose, a mouth, and ears, from the registered images stored in the storage unit **22***b* at Step S**410** as characterizing quantities (Step S**411**). The authenticating unit **22***h* then stores the characterizing quantities extracted at Step S**411** in the storage unit **22***b*, in a manner associated with the registered image stored at Step S**410** (Step S**412**), and the process is ended.

(2) Authenticating Process

FIG. **12** is a flowchart illustrating an authenticating process according to the second embodiment. This authenticating process is initiated when the sensor unit **21***a* detects a user entering the pass-through area of the gate.

As illustrated in FIG. **12**, when the sensor unit **21***a* detects a user entering the pass-through area of the gate (Step S**601**), the image capturing control unit **21***f* notifies the authentication apparatus **22** of the user entering the pass-through area of the gate (Step S**602**). The retry control unit **22***j* receiving the notification at Step S**602** initializes the retry count R by setting the retry count R to zero (Step S**603**).

The determining unit **21***g* in the authentication apparatus **22** then executes the "divisor determining process" for determining the divisor N by which the exposure time E is divided (Step S**604**). At Step S**604**, the determining unit **21***g* can execute the same process as that explained in the first embodiment (see FIG. **8**).

The image capturing control unit **21***f* then executes the following process using the image capturing parameters including the divisor N determined by the determining unit **21***g*. In other words, the image capturing control unit **21***f* executes the "image capturing process" in which N pieces of OFF images and N pieces of ON images are captured in the order of N/2 pieces of OFF images, N pieces of ON images, and N/2 pieces of OFF images (Step S**605**). At Step S**605**, the image capturing control unit **21***f* can execute the same process as that explained in the first embodiment (see FIG. **9**).

The computing unit **21***h* then determines N pairs of an OFF image and an ON image, and computes N pieces of difference images from the respective pairs of an OFF image and an ON image (Step S**606**). The computing unit **21***h* then stores the N pieces of difference images computed at Step S**606** in the image storage unit **21***e* (Step S**607**).

The integrating unit **21***j* generates a single piece of integrated image from N pieces of difference images, by acquiring the sum of the pixel values across the N pieces of difference images stored in the image storage unit **21***e* (Step S**608**). The integrating unit **21***j* then stores the integrated image generated at Step S**608** in the image storage unit **21***e* (Step S**609**). The image capturing apparatus **21** then transfers the integrated image to the authentication apparatus **22** via the communicating unit **21***d* (Step S**610**).

The process from Step S**604** to Step S**610** is repeated until an image capturing ending instruction is received from the authentication apparatus **22** (No at Step S**611**). When an image capturing ending instruction is received (Yes at Step S**611**), the image capturing apparatus **21** ends the process.

At the same time, the authentication apparatus **22** stores the integrated image received at Step S**610** in the storage unit **22***b* (Step S**612**). The authenticating unit **22***h* then extracts characterizing quantities from the integrated image stored in the storage unit **22***b* at Step S**612** (Step S**613**).

The authenticating unit **22***h* then computes a similarity S between the characterizing quantities extracted from the integrated image of the user at Step S**613** and the characterizing quantities of each of the registered images stored in the storage unit **22***b* (Step S**614**).

The authenticating unit **22***h* then determines if there is any registered image resulting in a similarity S higher than the predetermined threshold (Step S**615**). If there is no registered image resulting in a similarity S equal to or higher than the threshold (No at Step S**615**), the retry control unit **22***j* increments the retry count R (Step S**616**), and determines if the retry count R is equal to or higher than the predetermined threshold (Step S**617**). The authentication apparatus **22** repeats the process from Step S**612** to Step S**616** until the retry count R reaches a value equal to or higher than the predetermined threshold (No at Step S**617**).

If there is a registered image resulting in a similarity S equal to or higher than the threshold (Yes at Step S**615**), or if the retry count R reaches a value equal to or higher than the threshold (Yes at Step S**617**) the following process is executed. In other words, the authenticating unit **22***h* notifies the image capturing apparatus **21** of an image capturing ending instruction (Step S**618**), outputs the authentication result of successful authentication or authentication failure to the image capturing apparatus **21** and to the unlocking device not illustrated (Step S**619**), and ends the process.

Advantageous Effects Achieved by Second Embodiment

As described above, the face authentication system **20** according to the second embodiment turns OFF the illumination unit **11***b* and captures OFF images before and after N pieces of ON images are captured, in the same manner as in the first embodiment described above. Therefore, the face authentication system **20** according to the second embodiment can reduce the frequency at which the illumination is switched from ON to OFF or from OFF to ON, and the frequency of and the time for null write can be reduced. As a result, idle time for capturing images can be reduced. Therefore, in the face authentication system **20** according to the second embodiment as well, the image capturing time can be reduced.

Furthermore, in the face authentication system **20** according to the second embodiment, the image capturing apparatus **21** performs the process of computing the difference between an OFF image and an ON image, the process of integrating the difference images, and the like. Therefore, in the face authentication system **20** according to the second embodiment, only one piece of integrated image can be transferred from the image capturing apparatus **21** to the authentication apparatus **22**, without transferring the N pieces of OFF images and the N pieces of ON images. Therefore, the communication traffic between the image capturing apparatus **21** and the authentication apparatus **22** can be reduced. Hence, for example, a communication load on a network connecting the image capturing apparatus **21** and the authentication apparatus **22** can be reduced. As a result, a high speed authenticating process can be realized.

Furthermore, in the face authentication system **20** according to the second embodiment, because the image capturing time is reduced, extension in the image capturing time can be suppressed even when used is an image sensor capturing images at a low rate and a long interval. For this reason, because an inexpensive image sensor can be used, costs can be reduced.

Furthermore, because the ON images are captured continuously at the center of the image capturing sequence, the influence of the variations in the external light and the subject can be reduced. This is because an ON image has higher luminance, an ON image is more influenced by such variations than an OFF image. By capturing the ON images continuously at the center of the image capturing sequence, the influence of such variations can be further reduced.

Explained in the second embodiment is an example in which the face authentication system **20** is used in controlling an entry and exit of user so that the user is permitted or not permitted to make an entry or exit depending on the authentication result output from the authentication apparatus **22**. Alternatively, the face authentication system **20** may be used for other purposes. For example, the face authentication system **20** may also be used in login management in which a login to an information processing apparatus such as a personal computer is permitted or not permitted depending on the authentication result.

[c] Third Embodiment

Explained in the second embodiment is an example in which the authentication apparatus **22** is caused to execute a face authentication using an integrated image. However, an

integrated image may also be used in determining the material of an object, without limitation to a face authentication. Therefore, explained in a third embodiment of the present invention is an example in which a determination apparatus **32** is caused to determine the material of an object using an integrated image.

Configuration of Material Determining System

FIG. **13** is a block diagram illustrating functional configurations of apparatuses included in a material determining system according to the third embodiment. A material determining system **30** illustrated in FIG. **13** determines the material of an object by comparing an integrated image of the object generated using an illumination unit **31***b*A with an integrated image of the object generated using an illumination unit **31***b*B. In the following description of the third embodiment, as an example, it is assumed that the material determination is used in determining if an object is made of a material α or a material β.

As illustrated in FIG. **13**, this material determining system **30** includes an image capturing apparatus **31** and the determination apparatus **32**. Among these apparatuses, the image capturing apparatus **31** is installed at a position enabling an object whose material is to be determined to be placed in the angle of view of the image capturing apparatus **31** so that images of the object whose material is to be determined can be captured, as an example. The determination apparatus **32** may be implemented as a server connected to a plurality of image capturing apparatuses **31**, as an example. Alternatively, a function for executing the material determination may be incorporated into the image capturing apparatus **31** so that the material determination is performed on standalone basis.

Configuration of Image Capturing Apparatus **31**

To begin with, the functional configuration of the image capturing apparatus **31** according to the third embodiment will be explained. The image capturing apparatus **31** illustrated in FIG. **13** includes the following functional units, instead of the sensor unit **21***a*, the illumination unit **21***b*, the image sensor **21***c*, the communicating unit **21***d*, the image storage unit **21***e*, the image capturing control unit **21***f*, the determining unit **21***g*, the computing unit **21***h*, and the integrating unit **21***j* included in the image capturing apparatus **21** illustrated in FIG. **10**. In other words, the image capturing apparatus **31** includes a sensor unit **31***a*, the illumination unit **31***b*A, the illumination unit **31***b*B, an image sensor **31***c*, a communicating unit **31***d*, an image storage unit **31***e*, an image capturing control unit **31***f*, a determining unit **31***g*, a computing unit **31***h*, and a integrating unit **31***j*.

The sensor unit **31***a*, an illumination unit **31***b*, the image sensor **31***c*, the communicating unit **31***d*, the image storage unit **31***e*, the image capturing control unit **31***f*, the determining unit **31***g*, the computing unit **31***h*, and the integrating unit **31***j* have basic functions that are the same as those of the respective functional units illustrated in FIG. **10**. Therefore, only the differences are explained hereunder.

Among these units, the sensor unit **31***a* is different from the sensor unit **21***a* illustrated in FIG. **10** in that the sensor unit **31***a* detects an object whose material is to be determined. Therefore, the sensor unit **31***a* monitors an area in which the object whose material is to be determined is installed, e.g., a radius of 1 meter, from the image capturing apparatus **31**. When the sensor unit **31***a* detects any object in such an installation area, the sensor unit **31***a* notifies the image capturing control unit **31***f*, which will be described later, that an object is installed in the installation area.

The illumination unit **31***b*A is different from the illumination unit **21***b* illustrated in FIG. **10** in that the illumination unit **31***b*A illuminates the object whose material is to be determined. Therefore, the illumination unit **31***b*A is installed at a position for illuminating the central portion of a region to be determined of the object that is installed in the installation area detected by the sensor unit **31***a*, for example. When the illumination unit **31***b*A has directivity, the illumination unit **31***b*A may be provided with a mechanical unit for allowing the direction to which the illuminating light is output to be adjusted depending on the position of an object in the installation area. In the description hereunder, it is assumed that the illumination unit **31***b*A uses an illumination A with a wavelength at λ_A as a light source.

The illumination unit **31***b*B is different from the illumination unit **31***b*A in that the wavelength of the light source is longer than that of the illumination unit **31***b*A. In the description below, it is assumed that the illumination unit **31***b*B uses an illumination B having a wavelength at λ_B is that is longer than λ_A as a light source.

The image sensor **31***c* is different from the image sensor **21***c* illustrated in FIG. **10** in that the image sensor **31***c* is installed at a position where the object in the installation area is allowed to be imaged on the image sensor **21***c* via a lens not illustrated. The image sensor **31***c* may also include a mechanical unit for adjusting the angular field of the image capturing apparatus **31** depending on the position of the object in the installation area so that the region to be determined of the object can be imaged on the image sensor **31***c*. The image capturing control unit **31***f*, which will be described later, stores the images captured by the image sensor **31***c* in the image storage unit **31***e*.

The communicating unit **31***d* is different from the communicating unit **21***d* illustrated in FIG. **10** in that the communicating unit **31***d* transmits and receives different types of data to and from other apparatuses including the determination apparatus **32**. For example, the communicating unit **31***d* transfers an integrated image for the illumination unit **31***b*A and an integrated image for the illumination unit **31***b*B both of which are generated by the integrating unit **31***j* to be described later to the determination apparatus **32**.

The image storage unit **31***e* stores therein different types of data from those stored in the image storage unit **21***e* illustrated in FIG. **10**. As described above, in the third embodiment, the image capturing apparatus **31** captures the OFF images and the ON images using the illumination units **31***b*A and **31***b*B, computes difference images, and generates an integrated image. Therefore, the image storage unit **31***e* stores therein original images such as OFF images and ON images for the illumination units **31***b*A and **31***b*B acquired from the image sensor **31***c*, difference images, and an integrated image.

The image capturing control unit **31***f* is different from the image capturing control unit **21***f* illustrated in FIG. **10** in that image capturing control unit **31***f* captures not only ON images with the illumination unit **31***b*A but also ON images with the illumination unit **31***b*B. As an example, the image capturing control unit **31***f* turns ON the illumination unit **31***b*A and turns OFF the illumination unit **31***b*B, and captures N pieces of ON images with the illumination unit **31***b*A before and after turning OFF the illumination unit **31***b*A, turning ON the illumination unit **31***b*B, and capturing N pieces if ON images with the illumination unit **31***b*B. Furthermore, the image capturing control unit **31***f* also turns OFF the illumination unit **31***b*A and the illumination unit **31***b*B, and captures 2*N pieces of OFF images before and after turning ON the illumination unit **31***b*A, turning OFF the illumination unit **31***b*B, and capturing N pieces of ON images with the illumination unit **31***b*A. For example, after turning OFF the illumination unit **31***b*A and the illumination unit **31***b*B and capturing N pieces of OFF images, the image capturing control unit **31***f* turns ON the

illumination unit **31***b*A and captures N/2 pieces of ON images with the illumination unit **31***b*A. The image capturing control unit **31***f* then turns OFF the illumination unit **31***b*A and turns ON the illumination unit **31***b*B, and captures N pieces of ON images with the illumination unit **31***b*B. The image capturing control unit **31***f* then turns OFF the illumination unit **31***b*B, turns ON the illumination unit **31***b*A, and captures N/2 pieces of ON images with the illumination unit **31***b*A, and then turns OFF the illumination unit **31***b*A and the illumination unit **31***b*B and captures N pieces of OFF images.

FIG. **14** is a schematic of an example of the image capturing sequence. Illustrated as an example in FIG. **14** is an image capturing sequence of when the divisor N is "4". As illustrated in FIG. **14**, the image capturing control unit **31***f* keeps the illumination unit **31***b*A and the illumination unit **31***b*B OFF for a period from time H**0** to time H**4**, and closes the shutter temporarily at time H**1**, time H**2**, and time H**3**. In this manner, the image capturing control unit **31***f* stores an OFF image aA**1** acquired through the exposure over a period from "H**0** to H**1**", an OFF image aA**2** acquired through the exposure over a period from "H**1**to H**2**", an OFF image aB**1** acquired through the exposure over a period from "H**2** to H**3**", and an OFF image aB**2** acquired through the exposure over a period from "H**3** to H**4**" in the image storage unit **31***e* in the order described herein. The image capturing control unit **31***f* then switches the illumination unit **31***b*A from OFF to ON at time H**4**. At this time, the image capturing control unit **31***f* performs null write to the image storage unit **31***e* for an image acquired through the exposure over a period "H**4** to H**5**", assuming that switching from OFF to ON takes time from time H**4** to time H**5**.

The image capturing control unit **31***f* keeps the illumination unit **31***b*A ON for a period from time H**5** to time H**7**, closes the shutter temporarily at time H**6**. As a result, an ON image bA**1** acquired through the exposure over a period from "H**5** to H**6**" and an ON image bA**2** acquired through the exposure over a period from "H**6** to H**7**" are stored in the image storage unit **31***e* in the order described herein. The image capturing control unit **31***f* then switches the illumination unit **31***b*A from ON to OFF at time H**7**, and switches the illumination unit B from OFF to ON. The image capturing control unit **31***f* then performs null write to the image storage unit **31***e* for an image acquired through the exposure over a period "H**7** to H**8**". The image capturing control unit **31***f* then keeps the illumination unit **31***b*B ON for a period from time H**8** to time H**12**, and closes the shutter temporarily at time H**9**, time H**10**, and time H**11**. In this manner, the image capturing control unit **31***f* causes the image storage unit **31***e* to store therein an ON image bB**1** acquired through the exposure over a period from "H**8** to H**9**", an ON image bB**2** acquired through the exposure over a period from "H**9** to H**10**", an ON image b**83** acquired through the exposure over a period from "H**10** to H**11**", and an ON image bB**4** acquired through the exposure over a period from "H**11** to H**12**" in the order described herein. The image capturing control unit **31***f* then switches the illumination unit **31***b*A from OFF to ON, and switches the illumination unit B from ON to OFF at time H**12**. The image capturing control unit **31***f* then performs null write to the image storage unit **31***e* for an image acquired through the exposure over a period "H**12** to H**13**".

The image capturing control unit **31***f* then keeps the illumination unit **31***b*A ON for a period from time H**13** to time H**15**, and closes the shutter temporarily at time H**14**. As a result, an ON image bA**3** acquired through the exposure over a period from "H**13** to H**14** " and an ON image bA**4** acquired through the exposure over a period from "H**14** to H**15**" are stored in the image storage unit **31***e* in the order described herein. The image capturing control unit **31***f* then switches the illumination unit **31***b*A from ON to OFF at time H**15**. The image capturing control unit **31***f* then performs null write to the image storage unit **31***e* for an image acquired through the exposure over a period "H**15** to H**16**". The image capturing control unit **31***f* then keeps the illumination unit **31***b*A and the illumination unit **31***b*B OFF for a period from time H**16** to time H**20**, and closes the shutter temporarily at time H**17**, time H**18**, and time H**19**. In this manner, the image capturing control unit **31***f* causes the image storage unit **31***e* to store therein an OFF image aB**3** acquired through the exposure over a period from "H**16** to H**17**", an OFF image aB**4** acquired through the exposure over a period from "H**17** to H**18**", an OFF image aA**3** acquired through the exposure over a period from "H**18** to H**19**", and an OFF image aA**4** acquired through the exposure over a period from "H**19** to H**20**" in the order described herein.

The determining unit **31***g* is different from the determining unit **21***g* illustrated in FIG. **10** in that the determining unit **31***g* determines the divisor using information in which the intensity of the external light is associated with a divisor. As a possible implementation, the determining unit **31***g* determines the divisor N using information in which an output current is associated with a divisor. This information serves as an index for the intensity of external light, and is stored in an information storage unit **31***m* which is to be described later. FIG. **15** is a schematic of an example of information in which an output current is associated with a divisor. For example, when an output current measured with a measuring unit **31***k* to be described later is 35 milliamperes, the determining unit **31***g* determines "4" as the divisor N. In determining the divisor N, in order to suppress saturation, the determining unit **31***g* determines the divisor N using an illumination whose optimal exposure time is the longest. For example, when the optimal exposure time with the light from the illumination unit **31***b*B is longer than that with the illumination unit **31***b*A, the determining unit **31***g* causes the measuring unit **31***k* to measure the output current using the light of the illumination unit **31***b*B, and determines the divisor N. An image capturing instruction containing the divisor N thus determined and the exposure time E is then output to the image capturing control unit **11***f*.

The computing unit **31***h* is different from the computing unit **21***h* illustrated in FIG. **10** in that the computing unit **31***h* computes difference images for each of the illumination unit **31***b*A and the illumination unit **31***b*B. Therefore, in the example illustrated in FIG. **14**, the computing unit **31***h* establishes four pairs by pairing the OFF image aA**1** and the ON image bA**1**, pairing the OFF image aA**2** and the ON image bA**2**, pairing the OFF image aA**3** and the ON image bA**3**, and pairing the OFF image aA**4** and the ON image bA**4**. The computing unit **31***h* then computes a difference image A**1** for the illumination unit **31***b*A by computing pixel value differences between the pixels in the OFF image aA**1** and those in the ON image bA**1**. In the same manner, the computing unit **31***h* computes a difference image A**2** from the OFF image aA**2** and the ON image bA**2**, computes a difference image A**3** from the OFF image aA**3** and the ON image bA**3**, and computes a difference image A**4** from the OFF image aA**4** and the ON image bA**4**.

The computing unit **31***h* also establishes four pairs by paring the OFF image aB**1** and the ON image bB**1**, paring the OFF image aB**2** and the ON image bB**2**, paring the OFF image aB**3** and the ON image bB**3**, and paring the OFF image aB**4** and the ON image bB**4**. The computing unit **31***h* computes a difference image B**1** for the illumination unit **31***b*B by computing pixel value differences between the pixels in the

OFF image aB1 and those in the ON image bB1. In the same manner, the computing unit **31***h* computes a difference image B2 from the OFF image aB2 and the ON image b2, computes a difference image B3 from the OFF image aB3 and the ON image bB3, and computes a difference image B4 from the OFF image aB4 and the ON image bB4. In this manner, the computing unit **31***h* computes N pieces of difference images for the illumination unit **31***b*A and N pieces of difference images for the illumination unit **31***b*B. The computing unit **31***h* then stores N pieces of difference images for the illumination unit **31***b*A and those for the illumination unit **31***b*B in an image storage unit **31***e*.

The integrating unit **31***j* is different from the integrating unit **31***j* illustrated in FIG. **10** in that the integrating unit **31***j* generates an integrated image for each of the illumination unit **31***b*A and the illumination unit **31***b*B.

Furthermore, the image capturing apparatus **31** also includes the measuring unit **31***k* and the information storage unit **31***m*. Among these units, the measuring unit **31***k* is a processing unit that measures the intensity of external light. As a possible implementation, the measuring unit **31***k* measures an output current acquired by the generation of an electromotive force resulting from the photovoltaic effect achieved when the measuring unit **31***k* is illuminated with the light from the illumination, as an index of the external light intensity. The optimal exposure time differs depending on the illumination, because the light intensity of the illumination and the sensitivity of the image sensor vary depending on the wavelength of the illumination. Furthermore, saturation is more likely to be produced from an illumination with a long optimal exposure time than one with a short optimal exposure time. Therefore, in order to suppress saturation, the measuring unit **31***k* sets the wavelength of the light to be measured to the wavelength of the light whose optimal exposure time is the longest. An example of a possible implementation of the measuring unit **31***k* includes a detector such as a photodiode or a phototransistor.

The information storage unit **31***m* is a storage device storing therein information in which an intensity of the external light is associated with a divisor. As an example, the information storage unit **31***m* stores therein information in which an output current measured with the measuring unit **31***k* is associated with a divisor in advance. As an example, to the information in which an intensity of the external light is associated with a divisor, values acquired through experiments or the like are set in advance. In the example illustrated in FIG. **15**, this information is information having a table format in which a divisor corresponding to an output current range is set in the same row as the output current range. As another example, the information storage unit **31***m* is accessed, when an output current is measured with the measuring unit **31***k*, to read the information of the divisor corresponding to the output current thus measured.

Configuration of Determination Apparatus **32**

A functional configuration of the determination apparatus **32** according to the third embodiment will now be explained. The determination apparatus **32** illustrated in FIG. **13** includes a communicating unit **32***a* and a storage unit **32***b*, instead of the communicating unit **22***a*, and the storage unit **22***b* included in the authentication apparatus **22** illustrated in FIG. **10**.

Because the communicating unit **32***a* and the storage unit **32***b* have basic functions that are the same as those of the respective functional units illustrated in FIG. **10**, only the differences are explained hereunder.

Among these units, the communicating unit **32***a* transmits and receives different types of data to and from other apparatuses including the image capturing apparatus **31**, from those transmitted and received by the communicating unit **22***a* illustrated in FIG. **10**. For example, the communicating unit **32***a* receives an integrated image for the illumination unit **31***b*A and an integrated image for the illumination unit **31***b*B from the image capturing apparatus **31**.

The storage unit **32***b* stores therein different types of data from those stored in the storage unit **22***b* illustrated in FIG. **10**. As described earlier, in the third embodiment, the image capturing apparatus **31** transfers an integrated image for the illumination unit **31***b*A and the integrated image for the illumination unit **31***b*B to the determination apparatus **32**. Therefore, as an example, when the integrated image for the illumination unit **31***b*A and the integrated image for the illumination unit **31***b*B are received from the image capturing apparatus **31**, the storage unit **32***b* stores therein the integrated image for the illumination unit **31***b*A and the integrated image for the illumination unit **31***b*B. As another example, when a material determination is performed, the storage unit **32***b* is accessed by a determination unit **32***c*, which will be described later, making a reference to the integrated image for the illumination unit **31***b*A and the integrated image for the illumination unit **31***b*B.

The determination apparatus **32** further includes the determination unit **32***c*. The determination unit **32***c* is a processing unit that determines the material of an object, using the integrated images generated by the image capturing apparatus **31**. As a possible implementation, the determination unit **32***c* determines the material of an object by computing luminance ratio between the luminance in an image A that is an integrated image for the illumination unit **31***b*A and that in an image B that is an integrated image for the illumination unit **31***b*B. FIG. **16** is a graph illustrating an example of a relation between a wavelength and reflectance of different materials. As illustrated in FIG. **16**, reflectance of a material differs depending on the wavelength of the illuminating light. Therefore, the material of an object can be determined by comparing the luminance in an image captured when the object is illuminated with the light from the illumination unit **31***b*A at a wavelength λ_A and another image captured when the object is illuminated with the illumination unit **31***b*B at a wavelength λ_B. For example, the determination unit **32***c* sets a determined area D to the integrated images generated by the image capturing apparatus **31**. The determination unit **32***c* then computes R(x, y)=IA(x, y)/IB(x, y), which is the ratio between luminance IA(x, y) at coordinates (x, y) in the image A and luminance IB(x, y) at the coordinates (x, y) in the image B, for every point P(x, y) in the determined area D. The determination unit **32***c* then determines if the luminance ratio R(x, y) between the image A and the image B thus computed is lower than the predetermined threshold. If R(x, y) is lower than the predetermined threshold, the determination unit **32***c* determines that the object is made of material α. If R(x, y) is equal to or higher than the predetermined threshold, the determination unit **32***c* determines that the object is made of material β.

Sequence of Processes

The sequence of processes performed by the material determining system **30** according to the third embodiment will now be explained. In this section, (1) a determining process performed by the material determining system **30** will be explained to begin with, and (2) a divisor determining process and (3) an image capturing process included in the determining process will then be explained in detail.

(1) Determining Process

FIG. **17** is a flowchart illustrating the determining process according to the third embodiment. The determining process is initiated when the sensor unit **31***a* detects an object in the

installation area. As illustrated in FIG. **17**, when the sensor unit **31***a* detects an object in the installation area (Step S**801**), the determining unit **31***g* executes the "divisor determining process" for determining the divisor N by which the exposure time E is divided (Step S**802**).

The image capturing control unit **31***f* captures N pieces of OFF images, N/2 pieces of ON images with the illumination unit **31***b*A, and N pieces of ON images with the illumination unit **31***b*B in the order described herein, based on the image capturing instruction containing image capturing parameters including the divisor N determined by the determining unit **31***g*. The image capturing control unit **31***f* then captures N/2 pieces of ON images with the illumination unit **31***b*A and N pieces of OFF images in the order described herein. In this manner, the image capturing control unit **31***f* performs the "image capturing process" in which 2*N pieces of OFF images, N pieces of ON images with the illumination unit **31***b*A, and N pieces of ON images with the illumination unit **31***b*B are captured (Step S**803**).

The computing unit **31***h* then determines N pairs of an OFF image and an ON image with the illumination unit **31***b*A, and N pairs of an OFF image and an ON image with the illumination unit **31***b*B. The computing unit **31***h* then computes N pieces of difference images from the respective pairs of an OFF image and an ON image for each of the illumination unit **31***b*A and the illumination unit **31***b*B (Step S**804**). The computing unit **31***h* stores the N pieces of difference images for each of the illumination unit **31***b*A and the illumination unit **31***b*B computed at Step S**804** in the image storage unit **31***e* (Step S**805**).

The integrating unit **31***j* then acquires the sum of the pixel values across the N pieces of difference images for each of the illumination unit **31***b*A and the illumination unit **31***b*, stored in the image storage unit **31***e*. In this manner, the integrating unit **31***j* generates a single piece of integrated image for the illumination unit **31***b*A and a single piece of integrated image for the illumination unit **31***b*B, from the N pieces of difference images for the illumination unit **31***b*A and the N pieces of difference images for the illumination unit **31***b*B, respectively (Step S**806**). The integrating unit **31***j* then stores the integrated images generated at Step S**806** in the image storage unit **31***e* (Step S**807**). The image capturing apparatus **31** transfers the integrated image for the illumination unit **31***b*A and the integrated image for the illumination unit **31***b*B to the determination apparatus **32** via the communicating unit **31***d* (Step S**808**).

The determination apparatus **32** stores the integrated image for the illumination unit **31***b*A and the integrated image for the illumination unit **31***b*B in the storage unit **32***b* (Step S**809**). The determination unit **32***c* then computes a luminance ratio R from the integrated image for the illumination unit **31***b*A and the integrated image for the illumination unit **31***b*B stored at Step S**809** in the storage unit **32***b* (Step S**810**).

If the luminance ratio R is equal to or higher than the predetermined threshold (Yes at Step S**811**), the determination unit **32***c* determines that the object is made of a material β (Step S**812**), and the process is ended. If the luminance ratio R is lower than the predetermined threshold (No at Step S**811**), the determination unit **32***c* determines that the object is made of a material α (Step S**813**), and the process is ended.

(2) Divisor Determining Process

FIG. **18** is a flowchart illustrating a divisor determining process according to the third embodiment. This process is initiated when the process at Step S**801** is executed in the determining process illustrated in FIG. **17**, in other words, when the sensor unit **31***a* detects an object.

As illustrated in FIG. **18**, the measuring unit **31***k* measures the output current (Step S**901**). The determining unit **31***g* then determines the divisor N from the output current measured with the measuring unit by referring to the associating information that is the information in which an output current is associated with a divisor (Step S**902**). The determining unit **31***g* then outputs an image capturing instruction containing the divisor N thus determined to the image capturing control unit **31***f* (Step S**903**), and the process is ended.

(3) Image Capturing Process

FIG. **19** is a flowchart illustrating the image capturing process according to the third embodiment. This image capturing process is initiated when an image capturing instruction is received from the determining unit **31***g*.

As illustrated in FIG. **19**, the image capturing control unit **31***f* computes the unit exposure time E' representing an exposure time for a single piece of image, by dividing the exposure time E by the divisor N (Step S**1001**).

The image capturing control unit **31***f* then turns OFF the illumination unit **31***b*A and the illumination unit **31***b*B, and captures N pieces of OFF images (Step S**1002**). The image capturing control unit **31***f* then turns ON the illumination unit **31***b*A, keeps the illumination unit **31***b*B OFF, and captures N/2 pieces of ON images with the illumination unit **31***b*A (Step S**1003**). The image capturing control unit **31***f* then turns OFF the illumination unit **31***b*A, turns ON the illumination unit **31***b*B, and captures N pieces of ON images with the illumination unit **31***b*B (Step S**1004**). The image capturing control unit **31***f* then turns ON the illumination unit **31***b*A, turns OFF the illumination unit **31***b*B, and captures N/2 pieces of ON images with the illumination unit **31***b*A (Step S**1005**). The image capturing control unit **31***f* then turns OFF the illumination unit **31***b*A and the illumination unit **31***b*B, and captures N pieces of OFF images (Step S**1006**).

Finally, the image capturing control unit **31***f* stores the N pieces of OFF images, the N pieces of ON images with the illumination unit **31***b*A, and the N pieces of ON images with the illumination unit **31***b*B acquired through the process at Step S**1002** to Step S**1006** in the image storage unit **31***e* (Step S**1007**), and the process is ended.

Advantageous Effects Achieved by Third Embodiment

As described above, the material determining system **30** according to the third embodiment captures OFF images before and after capturing the ON images. Because the material determining system **30** according to the third embodiment can reduce the frequency at which the illumination is switched from ON to OFF or from OFF to ON, the frequency of and the time for null write can be reduced. As a result, idle time for capturing images can be reduced. Hence, the material determining system **30** according to the third embodiment can reduce the image capturing time.

Furthermore, the material determining system **30** according to the third embodiment determines the divisor using an apparatus for measuring an output current and information in which an output current is associated with a divisor. Therefore, with the material determining system **30** according to the third embodiment, because the process for determining the divisor can be simplified, the image capturing time can be reduced. As an example, because capturing of ON images for determining the divisor and the computation of the external light evaluation value can be omitted, the image capturing time can be reduced. As another example, because when the external light is lower than the predetermined threshold, the process of computing the difference images and the process of generating the integrated image can be omitted by setting the divisor to zero, the image capturing time can be reduced.

Furthermore, in the material determining system **30** according to the third embodiment, because the image capturing time is reduced, extension in the image capturing time can be suppressed, even when used is an image sensor capturing images at a low rate and a long interval. Because an inexpensive image sensor can be used, costs can be reduced.

Furthermore, because the ON images are captured continuously at the center of the image capturing sequence, the influence of the variations in the external light and the subject can be reduced. This is because an ON image has higher luminance, an ON image is more influenced by such variations than an OFF image. By capturing the ON images continuously at the center of the image capturing sequence, the influence of such variations can be further reduced.

Furthermore, because the material determining system **30** according to the third embodiment determines the divisor based on an illumination whose optimal exposure time is the longest, saturation can be suppressed. Therefore, the determination accuracy can be improved.

Furthermore, in the material determining system **30** according to the third embodiment, capturing of images with the illumination whose optimal exposure time is the longest is positioned at the center of the image capturing sequence. In the material determining system **30** according to the third embodiment, because capturing of images with the largest amount of information is positioned at the center of the image capturing sequence, the influence of variations such as positional changes in the object or changes in the external light intensity can be reduced.

[d] Fourth Embodiment

Some embodiments related to the apparatuses according to the present invention are described so far, but the present invention may be implemented in various forms other than those disclosed in the embodiments. Other embodiments included in the present invention will now be explained.

Types of Subject to be Authenticated

Explained in the second embodiment is an example in which a face authentication is performed as a biometric authentication. However, the authenticated region is not limited to a face, but other biometric information such as a fingerprint or a palm vein may be used. For example, in the palm vein authentication, a palm that is the subject is irradiated with an illumination having a high transmittance to a human body, and an image capturing apparatus is caused to capture a reflected light. The person is then authenticated using a subdermal vein pattern captured by the image capturing apparatus as characteristics to be authenticated. Because a palm vein authentication uses a vein pattern that is usually invisible to human eyes in the authentication, the risk of leakage of characteristics to be authenticated is low. Therefore, such a palm vein authentication can be used as a personal authentication technology mainly in high-security fields, such as in a bank automatic tellers machine (ATM). Furthermore, because a palm vein authentication is a non-contact authentication not allowing the subject to touch the sensor, the user is forced to hold his/her hand over the sensor for a longer time when the image capturing time is extended. Therefore, the convenience can be improved by reducing the image capturing time.

Parallel Processing of Image Generation

Used in the example explained in the second embodiment and the third embodiment is an approach in which the OFF images and ON images, the difference images, and the integrated image are generated sequentially. However, an approach in which these images are generated in parallel may also be used. For example, the process of generating the difference image may be initiated once a single piece of OFF image and a single piece of ON image are generated, and the process of integrating the difference images for generating an integrated image may be initiated sequentially every time two pieces of difference images are generated. In this manner, generation of the OFF image and the ON image, generation of the difference image, and generation of the integrated image can be performed in parallel, without waiting for each of these processes of image generation to be completed. In this manner, the image capturing time can be reduced.

Exemplary Alternative of Divisor Determining Process

Used in the example explained in the first to the third embodiments is an approach in which the divisor is determined by capturing ON images for determining the divisor, in addition to the ON images used in computing difference images. However, the ON images used in computing the difference images may also be used in determining the divisor. For example, the N pieces of ON images captured after the N/2 pieces of OFF images are captured may be used as the ON images for determining the divisor.

FIG. **20** is a flowchart illustrating an example of such a divisor determining process. Explained hereunder is an example the second embodiment is applied with an approach in which the divisor is determined using the ON images that are used in computing difference images. The divisor determining process illustrated in FIG. **20** is initiated when a user is detected in the pass-through area of the gate, as illustrated in FIG. **12**. As illustrated in FIG. **20**, the determining unit **21***g* sets the initial value N_0 to the divisor N (Step S**701**). The determining unit **21***g* then sets the unit exposure time E' to E/N that is computed from the exposure time E and the divisor N (Step S**702**).

The determining unit **21***g* then causes the image capturing control unit **21***f* to capture N/2 pieces of OFF images based on the unit exposure time E' (Step S**703**). The determining unit **21***g* then causes the image capturing control unit **21***f* to capture N pieces of ON images (Step S**704**). The determining unit **21***g* computes the external light evaluation value Ex from the ON images captured at Step S**704** (Step S**705**). The determining unit **21***g* determines if the external light evaluation value Ex is lower than predetermined threshold Th (Step S**706**).

If the external light evaluation value Ex is equal to or higher than the predetermined threshold Th (No at Step S**706**), the determining unit **21***g* updates the divisor N to a value larger than the previous value, e.g., a value twice the previous divisor (Step S**707**). The system control then goes to Step S**702**, and the determining unit **21***g* repeats the process of updating the divisor, setting a unit exposure time E', capturing OFF images, capturing ON images, and computing the external light evaluation value Ex, until the external light evaluation value Ex reaches a value lower than the threshold Th. If the external light evaluation value Ex is lower than predetermined threshold Th (Yes at Step S**706**), the determining unit **21***g* outputs the divisor N used at Step S**701** or at Step S**707** to the image capturing control unit **21***f* (Step S**708**), and the process is ended. Once the divisor determining process is completed, the image capturing apparatus **21** performs the process at Step S**605** and thereafter illustrated in FIG. **12**.

At this time, because the divisor is determined using the N pieces of ON images captured by the image capturing control unit **21***f* used in computing difference images, capturing of ON images for determining the divisor, which are images not used in computing difference images, is not required. Therefore, the number of times the ON images are captured is reduced. Thus, the image capturing time can be reduced.

Explained above is an example in which the second embodiment is applied with an approach in which the divisor

is determined using the ON images used in computing difference images. However, such an approach may be applied to the first embodiment or the third embodiment, without limitation to the second embodiment.

Continuous Capturing

Used in the example explained in the first to the third embodiments is an approach in which the N pieces of OFF images and the N pieces of ON images are captured. However, the N pieces of OFF images and the N pieces of ON images may be captured continuously. FIG. **21** is a schematic of an example of such an image capturing sequence. Illustrated in FIG. **21** is an example of an image capturing sequence in which images are captured repeatedly when the divisor N is "4". Explained hereunder is an example in which the continuous capturing is applied to the second embodiment. As illustrated in FIG. **21**, the image capturing control unit **21***f* keeps the illumination unit **21***b* OFF during a period from time M**0** to time M**2**, and closes the shutter temporarily at time M**1**. The image capturing control unit **21***f* then causes the image storage unit **21***e* to store therein an OFF image c**1** acquired through the exposure over a period from "M**0** to M**1**", and causes the image storage unit **21***e* to store therein an OFF image c**2** acquired through the exposure over a period "M**1** to M**2**". The image capturing control unit **21***f* then switches the illumination unit **21***b* from OFF to ON at time M**2**. At this time, certain time is taken to complete switching from OFF to ON. Therefore, assuming that switching from OFF to ON takes time from time M**2** to time M**3**, the image capturing control unit **21***f* performs null write to the image storage unit **21***e* for an image acquired through the exposure over a period "M**2** to M**3**". Null is thus stored because any image acquired before switching to ON or OFF is completed is not used in the authentication.

The image capturing control unit **21***f* then keeps the illumination unit ON for a period from time M**3** to time M**7**, and closes the shutter temporarily at time M**4**, time M**5**, and time M**6**. As a result, the ON image d**1** acquired through the exposure over a period from "M**3** to M**4**", the ON image d**2** acquired through the exposure over a period from "M**4** to M**5**", the ON image d**3** acquired through the exposure over a period from "M**5** to M**6**", and the ON image d**4** acquired through the exposure over a period from "M**6** to M**7**" are stored in the image storage unit **21***e* in the order described herein. The image capturing control unit **21***f* switches the illumination unit **21***b* from ON to OFF at time M**7**. The image capturing control unit **21***f* performs null write to the image storage unit **21***e* for an image acquired through the exposure over a period from "M**7** to M**8**". The image capturing control unit **21***f* keeps the illumination unit **21***b* OFF for a period from time M**8** to time M**10**, and closes the shutter temporarily at time M**9** and time M**10**. After causing the image storage unit **21***e* to read an OFF image c**3** acquired through the exposure over a period "M**8** to M**9**", the image capturing control unit **21***f* causes the image storage unit **21***e* to store therein an OFF image c**4** acquired through the exposure over a period "M**9** to M**10**". This process is repeated until an image capturing ending instruction is received. Once N pieces of OFF images and N pieces of ON images are stored in the image storage unit **21***e*, the image capturing control unit **21***f* instructs the computing unit **21***h*, which will be described later, to compute difference images.

In the example explained above, the continuous capturing is applied to the second embodiment. However, the continuous capturing may be applied to the first embodiment or the third embodiment, without limitation to the second embodiment.

In this example, if it is determined that an OFF images used in computing the previous difference image or to be used in computing the subsequent difference image is captured under similar conditions to those under which the ON image to be used in computing the current difference image is captured than those under which the OFF image to be used in computing the current difference image is captured, the computing unit may compute the current difference image using the OFF image used in computing the previous difference image or to be used in computing the subsequent difference image.

For example, to explain using the example illustrated in FIG. **21**, when the difference images are to be computed using the ON images d**5** to d**8**, the computing unit may compute the difference images by pairing these ON images with the OFF images c**3** to c**6** (the alternative **1** in FIG. **21**), with the OFF images c**4** to c**7** (the alternative **2** in FIG. **21**), with the OFF images c**5** to c**8** (the alternative **3** in FIG. **21**), or with the OFF images c**6** to c**9** (the alternative **4** in FIG. **21**). Specifically, for example, for the alternative **2** in FIG. **21**, the computing unit establishes tour pairs by pairing the OFF image c**4** and the ON image d**5**, pairing the OFF image c**5** and the ON image d**6**, pairing the OFF image c**6** and the ON image d**7**, and pairing the OFF image c**7** and the ON image d**8**. The computing unit then computes a difference image cd**1** by computing pixel value differences between the pixels in the OFF image c**4** and those in the ON image d**5**. In the same manner, the computing unit computes a difference image cd**2** from the OFF image c**5** and the ON image d**6**, computes a difference image cd**3** from the OFF image c**6** and the ON image d**7**, and computes a difference image cd**4** from the OFF image c**7** and the ON image d**8**. In this manner, by pairing an ON image with an OFF image used in computing the previous difference image or an OFF image to be used in computing the subsequent difference image, an ON image can be paired with an OFF image captured under similar conditions as those under which the ON image is captured. In this manner, the influence of positional changes in the subject or changes in the external light intensity can be reduced.

Material Determination Using Illumination with Different Distribution Profile

Explained in the third embodiment is an example in which illuminations at different wavelengths are used. Alternatively, an illumination with a different distribution profile may be used. For example, an illumination provided with a lens may be used so that the subject is irradiated with a spot light converged by the lens. Use of a spot light for irradiating the subject enables the distance to the subject to be measured. Therefore, the determination accuracy can be improved.

Image Capturing Program

The various processes explained in the embodiments may be realized by causing a computer such as a personal computer or a workstation to execute a computer program prepared in advance. Explained now with reference to FIG. **22** is an example in which a computer executing an image capturing program having the same functions as those described in the embodiments.

FIG. **22** is a schematic for explaining an example of a computer for executing an image capturing program according to the first to the third embodiments. As illustrated in FIG. **22**, this computer **100** includes an operation unit **110***a*, a speaker **110***b*, a camera **110***c*, a display **120**, and a communicating unit **130**. The computer **100** also includes a CPU **150**, a read-only memory (ROM) **160**, a hard-disk drive (HDD) **170**, and a random access memory (RAM) **180**. These units are connected via a bus **140**.

An image capturing program **1708** achieving the same functions as those of the image capturing control unit **11***f*, the

determining unit **12***d*, the computing unit **12***e*, the integrating unit **12***f*, and the authenticating unit **12***g* described in the first embodiment is stored in advance in the HDD **170**, as illustrated in FIG. **22**. The functions achieved by the image capturing program **170***a* may be integrated or separated as appropriate, in the same manner as each of the image capturing control unit **11***f*, the determining unit **12***d*, the computing unit **12***e*, the integrating unit **12***f* and the authenticating unit **12***g* illustrated in FIG. **1**. Furthermore, the functions achieved by the image capturing program **170***a* may be integrated or separated as appropriate, in the same manner as the image capturing control unit **21***f*, the determining unit **21***g*, the computing unit **21***h*, the integrating unit **21***j*, and the authenticating unit **22***h* illustrated in FIG. **10**. Furthermore, the functions achieved by the image capturing program **170***a* may be integrated or separated as appropriate, in the same manner as the image capturing control unit **31***f*, the determining unit **31***g*, the computing unit **31***h*, the integrating unit **31***j*, and the determination unit **32***c* illustrated in FIG. **13**. In other words, all data to be stored in the HDD **170** does not always need to be stored in the HDD **170**, and only data to be used for the processes may be stored in the HDD **170**.

The CPU **150** then reads the image capturing program **170***a* from the HDD **170**, and loads the program onto the RAM **180**. In this manner, the image capturing program **170***a* functions as an image capturing process **180***a*, as illustrated in FIG. **22**. The image capturing process **180***a* loads various types of data read from the HDD **170** onto an area assigned to the image capturing process **180***a* on the RAM **180**, and executes various processes based on such data thus loaded. The image capturing process **180***a* includes the processes executed by the image capturing control unit **11***f*, the determining unit **12***d*, the computing unit **12***e*, the integrating unit **12***f*, and the authenticating unit **12***g* illustrated in FIG. **1**, e.g., the process illustrated in FIG. **7**. The image capturing process **180***a* also includes the process executed by the image capturing control unit **21***f*, the determining unit **21***g*, the computing unit **21***h*, the integrating unit **21***j*, and the authenticating unit **22***h* illustrated in FIG. **10**, e.g., the process illustrated in FIG. **12**. The image capturing process **180***a* also includes the process executed by the image capturing control unit **31***f*, the determining unit **31***g*, the computing unit **31***h*, the integrating unit **31***j*, and the determination unit **32***c* illustrated in FIG. **13**, e.g., the process illustrated in FIG. **17**. Not all of the processing units that are virtually realized on the CPU **150** do not always need to be operating on the CPU **150**, and only the processing units to be used for the process may be virtually realized on the CPU **150**.

The image capturing program **170***a* does not necessarily need to be stored in the HDD **170** or in the ROM **160** in advance. For example, each of these computer programs may be stored in a "portable physical medium" inserted into the computer **100** such as a flexible disk (FD), a compact disk read-only memory (CD-ROM), a digital versatile disk (DVD), a magneto-optical disk, or an integrated circuit (IC) card, and the computer **100** then may acquire each of the computer programs from the portable physical medium, and execute the computer program. Alternatively, each of the computer programs may be stored in another computer or a server connected to the computer **100** over a public circuit, the Internet, a local area network (LAN), or a wide area network (WAN), and the computer **100** may acquire each of the computer programs from the computer or the server, and execute the computer program.

An embodiment of the present invention can reduce an image capturing time.

All examples and conditional language recited herein are intended for pedagogical purposes of aiding the reader in understanding the invention and the concepts contributed by the inventor to further the art, and are not to be construed as limitations to such specifically recited examples and conditions, nor does the organization of such examples in the specification relate to a showing of the superiority and inferiority of the invention. Although the embodiments of the present invention have been described in detail, it should be understood that the various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

What is claimed is:

1. An image capturing method executed by an image capturing apparatus including an illumination that illuminates a subject, the image capturing method comprising:

continuously generating, using a processor, one or more OFF images in which the subject is captured with the illumination turned OFF, for a first number of times;

continuously generating, using the processor, ON images in which the subject is captured with the illumination turned ON, for a second number of times;

continuously generating, using the processor, one or more OFF images in which the subject is captured with the illumination turned OFF, for the first number of times after capturing the ON images;

computing, using the processor, a difference image between each of the generated ON images and an OFF image corresponding to the ON image among the generated OFF images; and

integrating, using the processor, the computed difference images, wherein

the generating includes turning OFF the illumination and capturing N/2 OFF images before and after N ON images are captured,

the N is a divisor by which an exposure time is divided, and

the exposure time is a time for which an image sensor is exposed to light that is imaged through a lens.

2. The image capturing method according to claim **1**, wherein the second number of times includes double of the first number of times.

3. The image capturing method according to claim **1**, wherein, the computing the difference image includes:

determining pairs of an ON image and an OFF image in order of times at which the ON images and the OFF images are generated, and

computing the difference image for each of the pairs of the ON image and the OFF image.

4. The image capturing method according to claim **1**, further comprising:

computing, from an ON image, an external light evaluation value representing intensity of external light in the ON image; and

determining the first number of times and the second number of times based on the external light evaluation value.

5. The image capturing method according to claim **1**, wherein

the computing the difference image includes computing a current difference image using an OFF image used in computing a previous difference image or an OFF image to be used in computing a subsequent difference image, when it is determined that the OFF image used in computing the previous difference image or the OFF image

to be used in computing the subsequent difference image is captured under conditions that the OFF image is more similar to an ON image to be used in computing the current difference image than an OFF image to be used in computing the current difference image.

6. The image capturing method according to claim **1**, further comprising determining the first number of times and the second number of times based on a captured image under a condition that a longest exposure time is used, when images are captured under different capturing conditions.

7. The image capturing method according to claim **6**, wherein, the determining the first number of times and the second number of times includes determining the first number of times and the second number of times based on the captured image under the condition that the longest exposure time is used, when the capturing conditions include a condition related to a wavelength of the illumination or a distribution profile of the illumination.

8. The image capturing method according to claim **1**, wherein the generating the ON images includes, when images are captured under different capturing conditions, generating ON images under a condition that a shorter exposure time is used before and after generating a ON image under a condition that a longest exposure time is used.

9. The image capturing method according to claim **8**, wherein, the generating the ON images includes, when the capturing conditions include a condition related to a wavelength of the illumination or a distribution profile of the illumination, generating ON images under the condition that the shorter exposure time is used before and after generating the ON image under the condition that the longest exposure time is used.

10. The image capturing method according to claim **1**, further comprising determining the first number of times and the second number of times based on intensity of external light measured with a measuring unit that measures intensity of external light.

11. The image capturing method according to claim **10**, wherein, the determining the first number of times and the second number of times includes employing the first number of times and the second number of times corresponding to the intensity of external light measured with the measuring unit from information in which intensities of external light are associated with first numbers of times and second numbers of times.

12. The image capturing method according to claim **1**, wherein, the generating the ON image, the generating the OFF image, the computing the difference image, and the integrating the difference images are performed independently.

13. An image capturing apparatus comprising:

a processor; and

a memory coupled to the processor, wherein the processor executes a process comprising:

continuously capturing one or more OFF images in which a subject is captured with an illumination illuminating the subject turned OFF, for a first number of times;

continuously capturing ON images in which the subject is captured with the illumination turned ON, for a second number of times after capturing the one or more OFF images;

continuously capturing one or more OFF images in which the subject is captured with the illumination turned OFF, for the first number of times after capturing the ON images;

computing a difference image between each of the captured ON images and an OFF image corresponding to the ON image among the captured OFF images; and

integrating the computed difference images, wherein

the capturing includes turning OFF the illumination and capturing N/2 OFF images before and after N ON images are captured,

the N is a divisor by which an exposure time is divided, and

the exposure time is a time for which an image sensor is exposed to light that is imaged through a lens.

14. A non-transitory computer readable storage medium having stored therein an image capturing program that causes a computer to execute a process comprising:

continuously capturing one or more OFF images in which a subject is captured with an illumination illuminating the subject turned OFF, for a first number of times;

continuously capturing ON images in which the subject is captured with the illumination turned ON, for a second number of times after capturing the one or more OFF images;

continuously capturing one or more OFF images in which the subject is captured with the illumination turned OFF, for the first number of times after capturing the ON images;

computing a difference image between each of the captured ON images and an OFF image corresponding to the ON image among the captured OFF images; and

integrating the computed difference images, wherein

the capturing includes turning OFF the illumination and capturing N/2 OFF images before and after N ON images are captured,

the N is a divisor by which an exposure time is divided, and

the exposure time is a time for which an image sensor is exposed to light that is imaged through a lens.

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